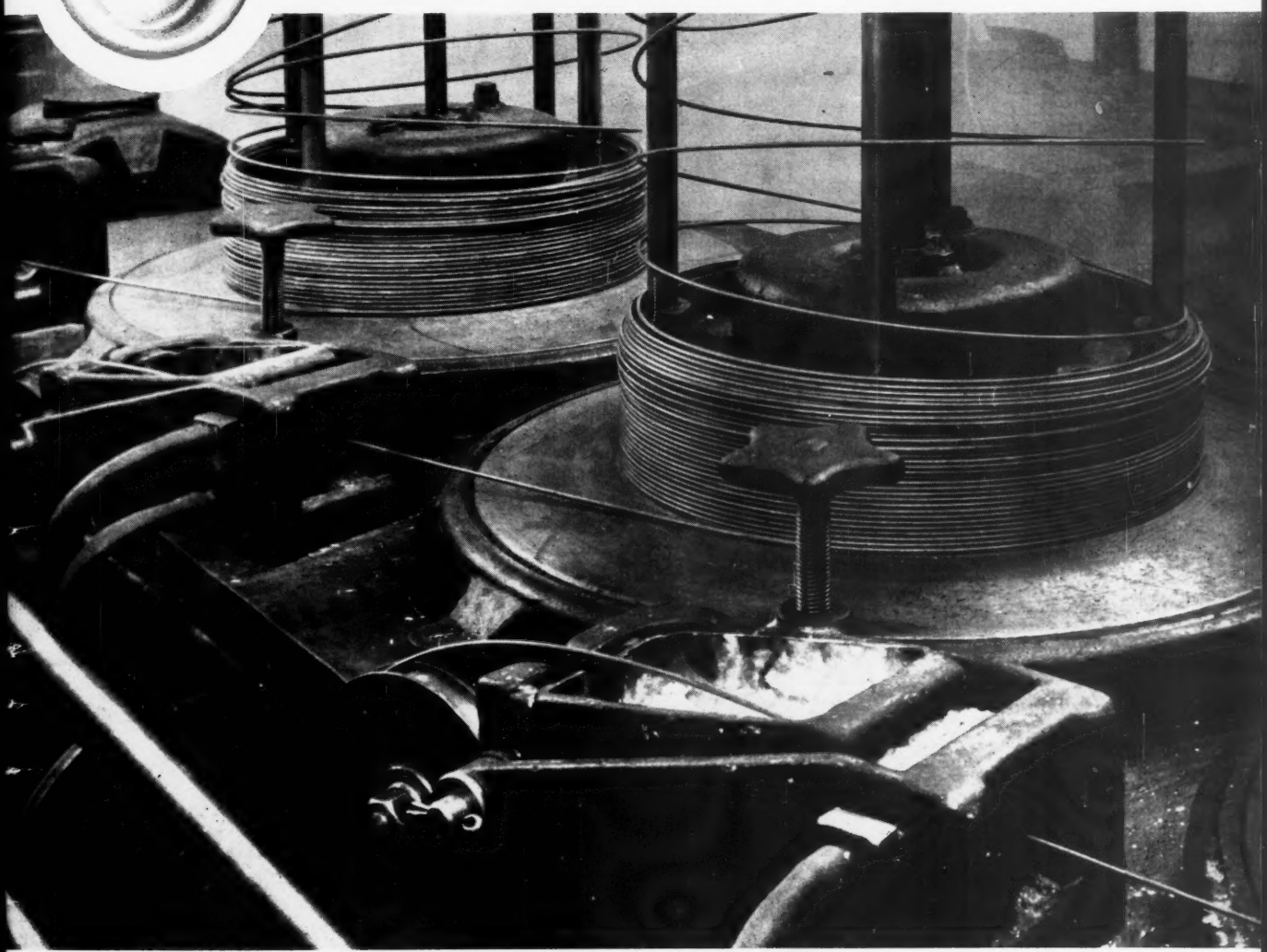
Glossary of Lubrication Terms (p. 199)

July-August, 1954

Vol. 10, No. 4

Lubrication ENGINEERING



Wire Drawing Lubricants (p. 190)

JOURNAL OF

THE AMERICAN SOCIETY OF LUBRICATION ENGINEERS

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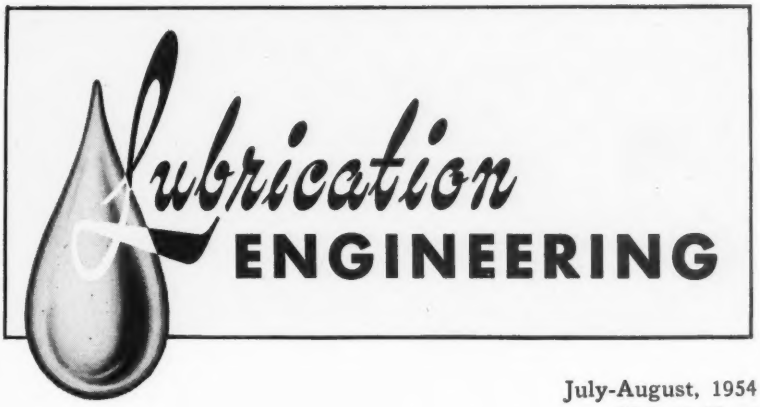

July-August, 1954
Vol. 10, No. 4

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(Cover Picture courtesy of Morgan Construction Co.)

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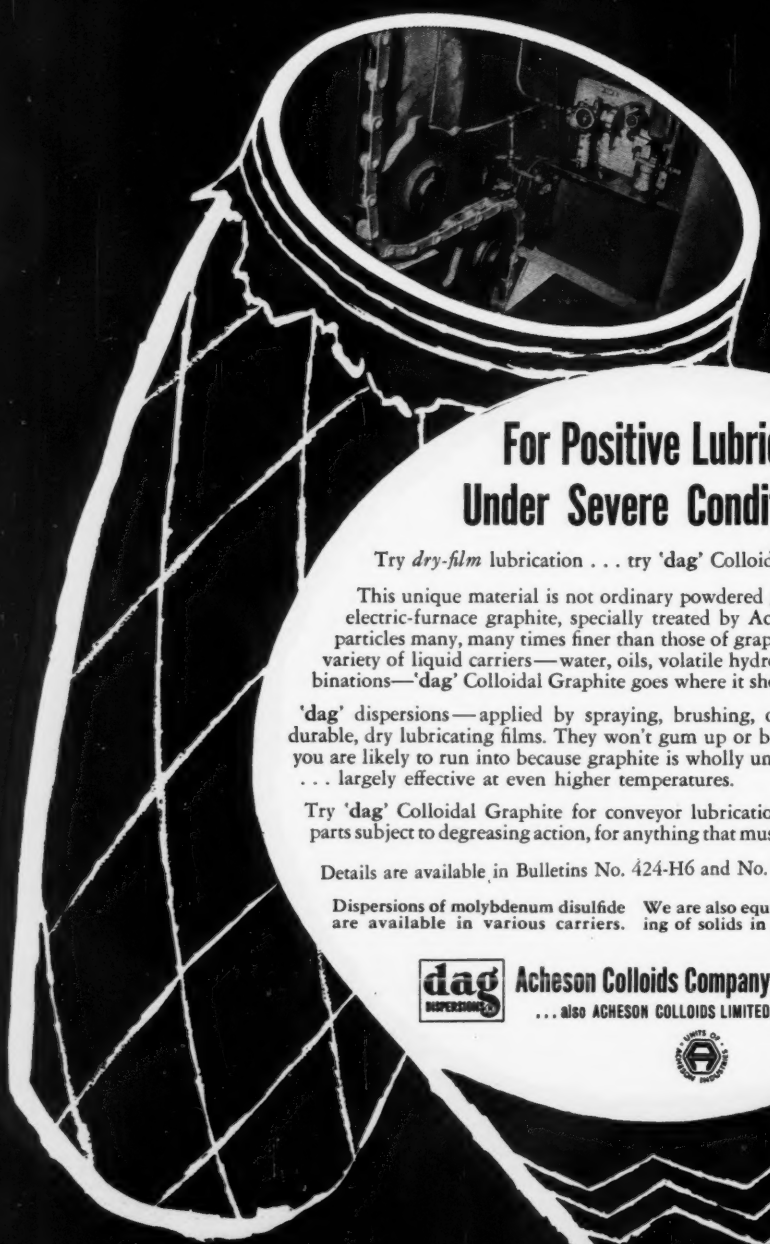

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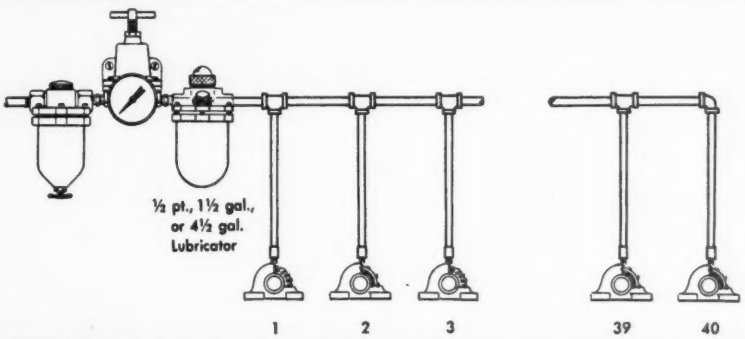

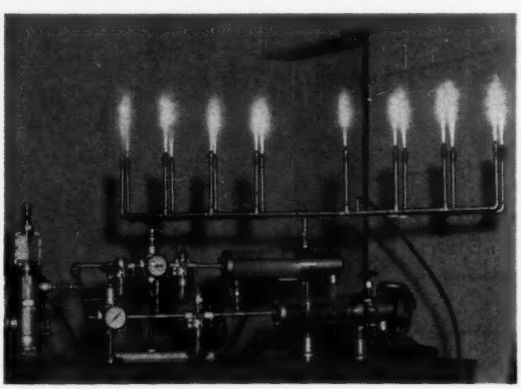

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by Du Pont

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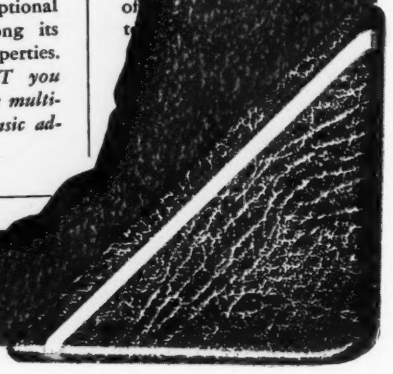
NOW—with Estersil GT you can easily prepare a unique multi-purpose grease with the basic advantages listed below . . .



1. Excellent Thermal Stability—Nonmelting Estersil GT greases show little change in consistency over a wide range of operating temperatures.

2. Excellent Shear Stability—This new thickener enables you to make greases with exceptional shear stability under *both* normal and *high* temperature conditions.

3. Water Resistance—The chemically bonded "raincoat" means greases with unusual resistance to wash out or break down in the presence of water.

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5. Superior Handling Qualities—Softer, more easily applied greases can be used for high temperature service because of the combined mechanical and thermal stability imparted by Estersil GT. These softer greases, of course, are more readily handled at low temperature than the more conventional types.

6. Ease of Manufacture—The completely synthetic preformed thickening structure allows reproducible grease preparation through a simple milling operation.

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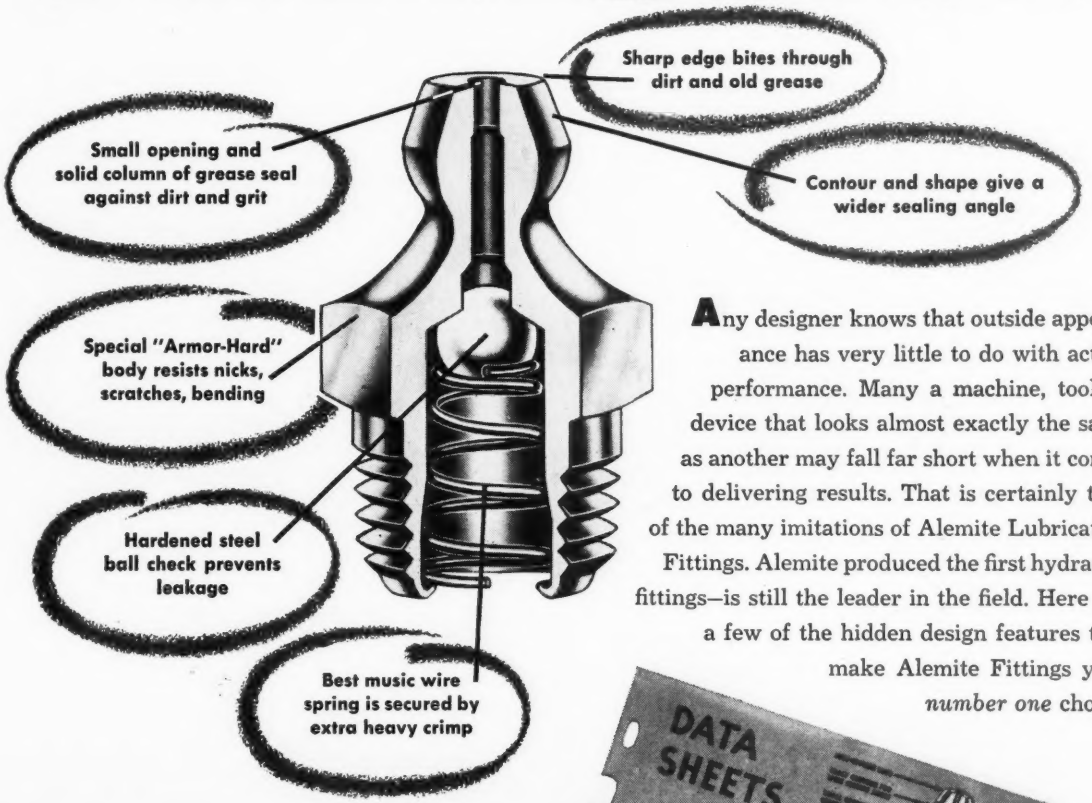
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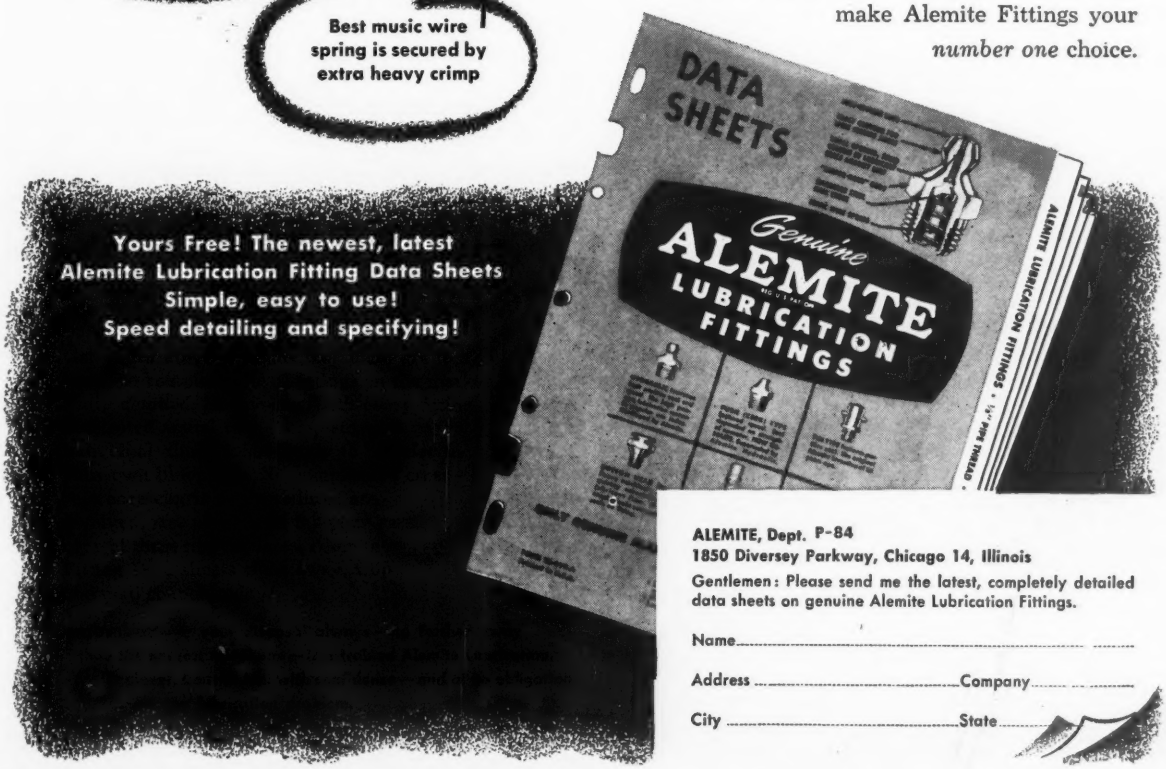

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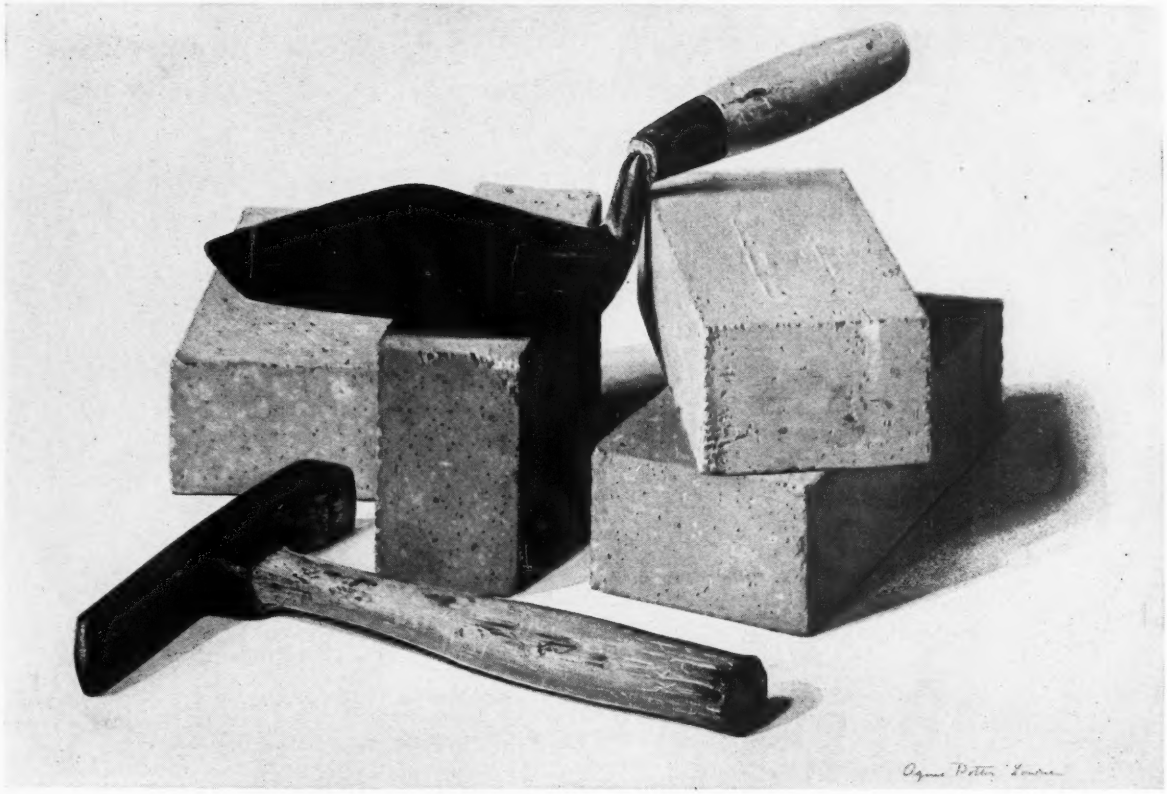

"Lining for the Furnaces" by Agnes Potter Lowrie, famed artist daughter of a noted steelmaker. In this second of a specially commissioned series, Mrs. Lowrie captures the deceptively soft, seldom seen texture of refractory brick so rugged it can withstand months of searing 3000° temperatures . . . Limited edition of 15 x 18 color prints available. Complimentary copy sent upon request.

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Whether it's building bridges or bombers, skyscrapers or pipelines . . . when America grows, it calls on steel. Year after year the industry has met the demand for more steel, better steel, faster and more efficient production. Today's speedy, almost automatic four-high mill, for instance, rolls in a single 8-hour shift more steel than the old-time hand mill produced in a week.

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Today almost every major steel producer is a user of Ironsides lubricants. Our unique position in the industry is due to our ability to formulate for individual applications and supply those special formulas in any quantity.

We like tough problems; we've solved a lot of them. For example, Palmoshield, replacement for palm oil and most significant advance in lubrication since World War II. If you have a problem, we'd like to help lick it. A letter will summon one of our engineers. Address The Ironsides Co., Columbus 16, Ohio.

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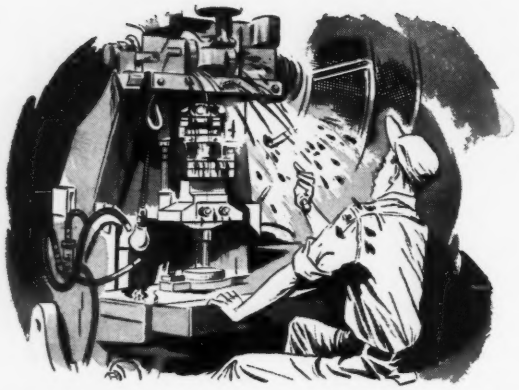
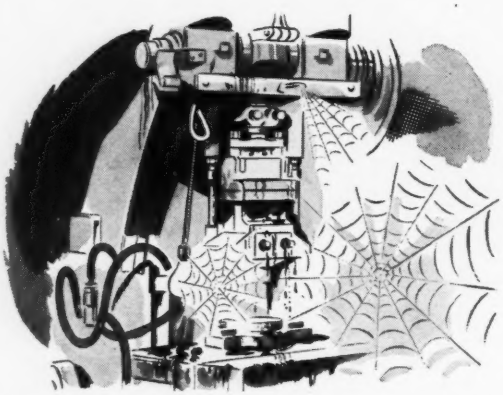


Metalworking firm was using heavy-duty stamping presses of an older type. Bearings were wearing excessively. Oil leaked constantly—on machines, floor and operators.

Lubricant loss was so severe that bearings frequently became so hot the machines had to be shut down until the bearings cooled. This cut sharply into production.



Bearings had to be replaced on an average of once every eight months. Repairs usually took four weeks, and during this time the machines as well as the floor space were completely non-productive.

Manufacturer switched to SUNTAC because it's especially compounded to cut leakage. No breakdown now for over three years. Oil consumption reduced 50%. Also using SUNTAC to lubricate other equipment.

Do you have machines with worn, leaky bearings? Or are you losing oil through excessive throw-off from rotating or sliding parts? SUNTAC is especially compounded to reduce drip, splash and squeezeout. Its greater adhesiveness makes it cling firmly to the parts it lubricates. Get all the facts about SUNTAC from your Sun Oil representative. Or write Dept. LE-8.

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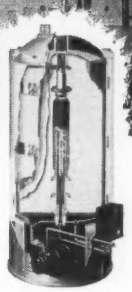

Honan-Crane Bulk Refill Purifier No. 21300 with built-in pump and motor services Birdsboro press pictured. Purifier operates 20 feet below floor level. This model is capable of servicing a 2,000-gallon system.

● Aircraft sections up to 10 by 30 feet are formed from ½" aluminum sheets on this Birdsboro hydro press. Its overall height is 51 feet and its weight a staggering 2,750,000 pounds. Because clean hydraulic oil is a vitally important factor in the operation of this mammoth press, Lockheed gives it the safe, dependable protection of a Honan-Crane Oil Purifier.

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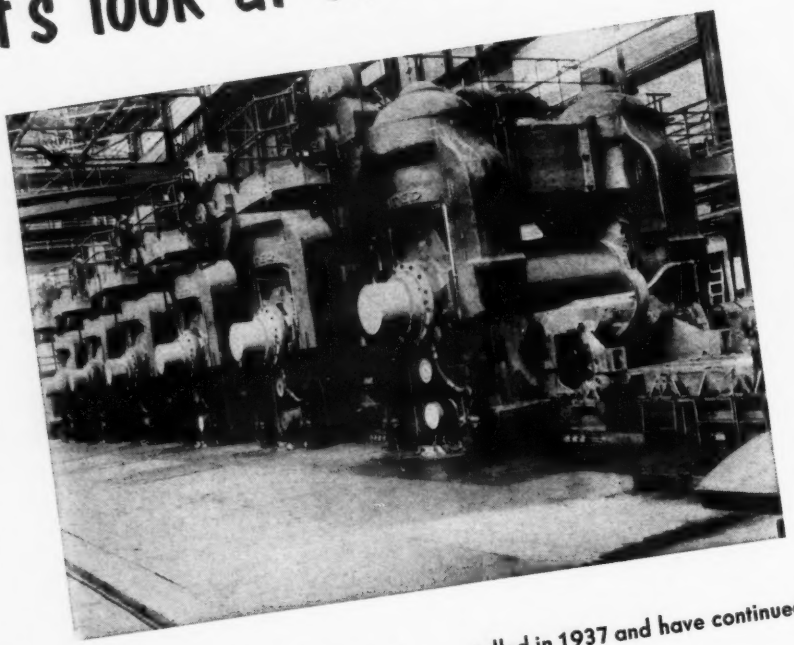

THIS picture shows Morgoil Bearings in operation in the four high hot strip mill at Corrigan-McKinney Works, Republic Steel Corp., Cleveland, Ohio. They were installed in 1937 and have continued to give outstanding service.

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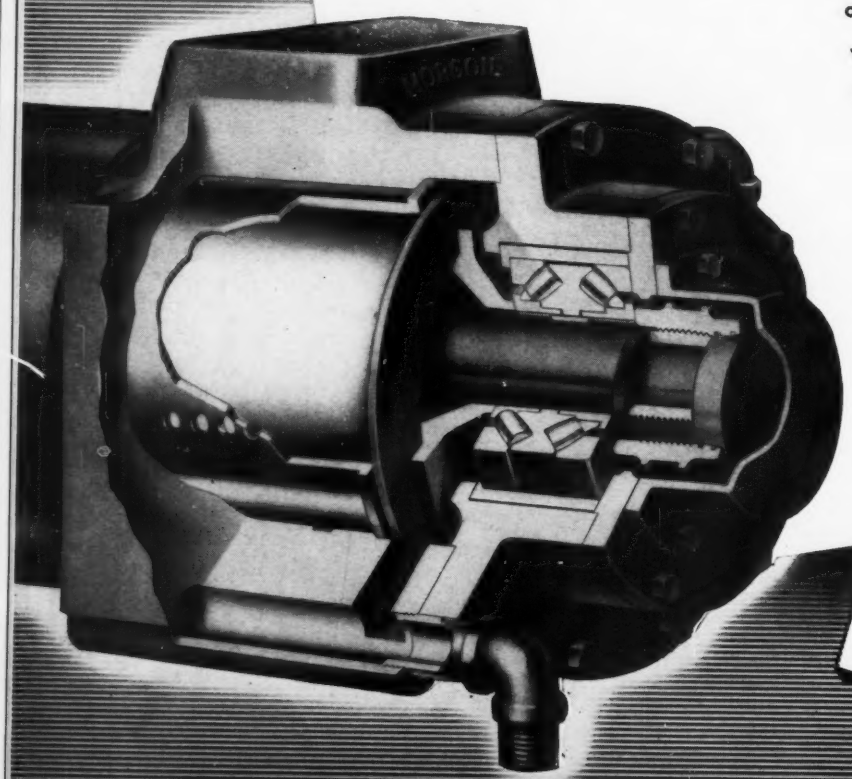

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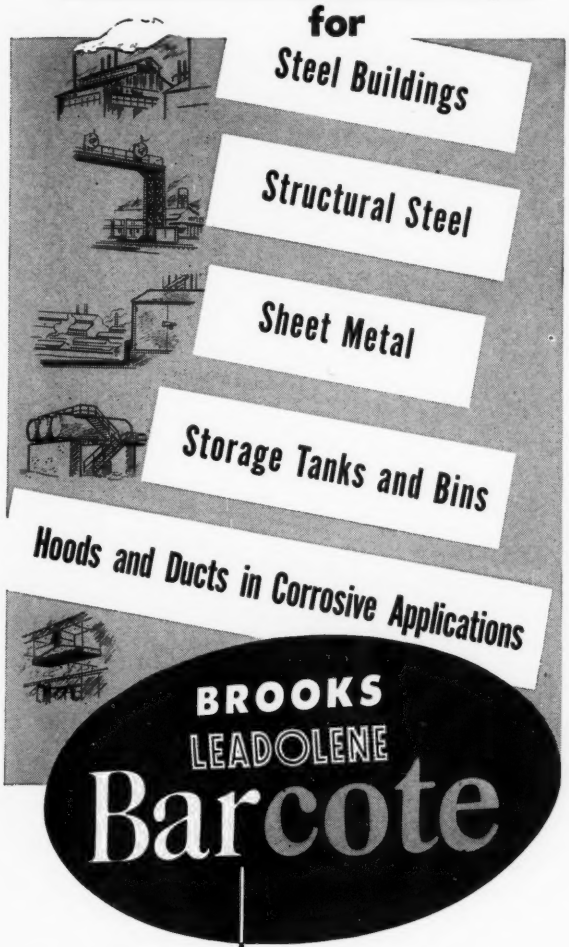

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NACA, Lewis Flight Prop. Lab.

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Westinghouse Research Labs.

R. L. Johnson (p. 193)
NACA, Lewis Flight Prop. Lab.

S. F. Murray (p. 193)
NACA Lewis Flight Prop. Lab.

E. Rabinowicz (p. 205)
Mass. Inst. of Tech.

L. Salz (p. 190)
Magnus Chemicals Co., Inc.

1955
ASLE Annual Meeting & Exhibit
Chicago, April 13-14-15

BALTIMORE

CONFERENCE on LUBRICATION

October 18 & 19, 1954

The ASME Lubrication Activity will hold its first Lubrication Conference in joint session with ASLE at the Lord Baltimore Hotel, Baltimore, Md., on October 18 & 19, 1954. Papers will be sponsored by both societies in five sessions, with a tentative schedule as follows:

Session I, Rolling Element Bearings. October 18, 10:00 A.M., E. E. Bisson, Chrmn.

High-Speed Ball Bearing Operation, by C. Moore
High Temperature Ball Bearing Operation in the Absence of a Lubricant, by Soren and Cataneo
Materials and Designs of Cages for High-Speed Roller Bearings, by Anderson and Nemeth

Session II, New Developments in Hydrodynamic Lubrication. October 18, 1:30 P.M., D. F. Wilcock, Chrmn.

Hydrodynamic Lubrication of a Cam and Cam Follower, by Davies
On the Solution of Reynolds' Equation for Slider Bearing Lubrication, IX — Stepped Slider Bearings, by F. Osterle, A. Charnes and E. Saibel
On the Solution of Reynolds' Equation for Slider Bearing Lubrication, X — The Journal Bearing with Circular Inlet, by F. Osterle and E. Saibel
Recent Advances in the Hydrodynamic Theory of Slider Bearing Lubrication, by E. Saibel
The Short Bearing Approximation for Plain Journal Bearings, by G. B. DuBois and Ocvirk

Session III, Bearing Instability. October 18, 8:00 P.M., F. C. Linn, Chrmn.

Oil Film Whirl — An Investigation of Disturbances Due to Oil Films in Journal Bearings, by B. L. Newkirk and J. F. Lewis
Turbulence in Water-Lubricated Thrust Bearings, by S. Abramovitz
Whip and Whirl in JB's, by B. Sternlicht and G. F. Boeker

Session IV, Hydrostatic Bearings. October 19, 9:30 A.M., D. D. Fuller, Chrmn.

An Analysis of Orifice Compensated Hydrostatic Journal Bearings, by Raimondi and Boyd
A Preliminary Investigation of an Air-Lubricated Hydrostatic Thrust Bearing, by L. Licht and D. D. Fuller
Behavior of Air in the Hydrostatic Lubrication of Loaded Spherical Bearings, by T. L. Corey, C. M. Taylor, Jr., H. H. Rowand, Jr., and E. M. Kipp
The Squeeze Film in Piston Pin and Spherical Bearings, by F. R. Archibald

Session V, Materials & Lubrication. October 19, 1:30 P.M., W. E. Campbell, Chrmn.

An Analysis of Recent Data on the Effects of Temperature and Pressure on the Viscosity of Lubricants, I — Paraffinic and Napthenic Base Oils, by R. B. Dow
Measurements of the Static Coefficient of Friction, by W. Claypoole
Power Loss in Non-Circular Section Sleeve Bearings, by O. Pinkus
A Progress Report on the Surface Endurance Limits of Engineering Materials, by Talbourdet

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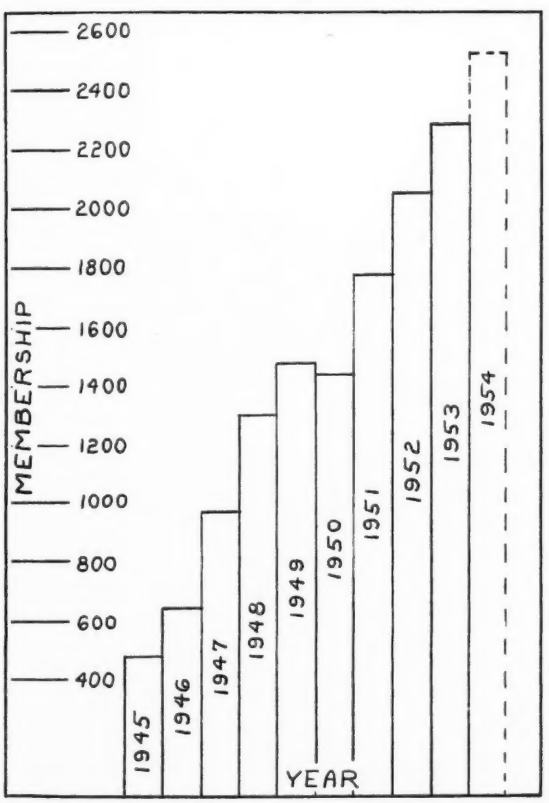
Lube Lines

ASLE OFFERS PAYMENT. As an indication of the growing importance of **Lubrication Engineering,** the demand for extra copies has increased sharply and the supply of back issues for June & August '53 has been exhausted. To help fulfill numerous requests, ASLE will pay 50c per copy for the first 100 copies of these issues returned to the National Office. Address: ASLE Publications, 84 E. Randolph St., Chicago 1, Ill.

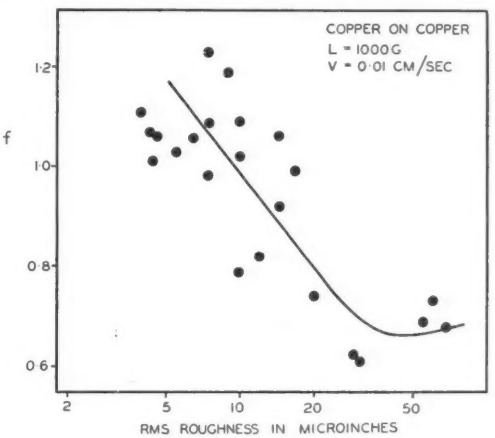
GROWTH OF ASLE. Except for 1950, membership in the American Society of Lubrication Engineers has continued a steady and almost uniform growth as illustrated in the accompanying bar chart. This increase in strength has resulted from a combination of activities in general and from the establishment of new Sections. On the basis of the rate of increase maintained over the past several years, membership should reach 2,550 by the end of 1954 (illustrated by broken lines). W. H. Fowler, Jr.



COMMENTARY on "Early Stages of Fretting of Copper, Iron & Steel" (D. Godfrey & J. M. Bailey, **Lubrication Engineering,** May-June, 1954, pp. 155-159) by Dr. E. Rabinowicz, Massachusetts Institute of Technology.

In the paper, "Early Stages of Fretting of Copper, Iron & Steel," the authors describe the initial stages of the fretting process, and their results show clearly the close relation between fretting damage and rectilinear sliding damage. One interesting phenomenon that seems characteristic of all their sliding combinations is the drop in friction that takes place after the first few cycles. Thus for copper on copper the initial friction coefficient of 1.2 soon drops to a value of about 0.6, and the authors point to this latter value as also being obtained in the sliding system copper oxide on copper oxide, which implies that the drop is of chemical origin. However, some recent work at M.I.T. suggests the existence of a physical phenomenon that produces the same effect.

Sliding experiments were carried out on a hemispherically ended copper rider on a copper flat, load 1000 g and velocity 0.01 cm/sec, these conditions being similar to those used by the authors. The roughness of the flat was varied by using different grades of emery paper, and the RMS roughness measured by a Brush surface analyser. The results, plotted in the figure, show a drop in friction from about 1.2 to about 0.6 as the surface roughness of the copper flat is increased.



A suggested explanation for this effect is as follows: The relatively large coefficient of friction for unlubricated copper on copper is due to a 'snowballing' effect as result of which each metallic junction during sliding increases more in area at the front than it decreases at the back. Thus, when smooth surfaces are used, large areas of contact and large coefficients of friction are observed. If rough surfaces are used the whole junction is broken before it can reach a large size whenever the junction meets a large depression in the surface, and thus smaller junctions and lower friction coefficients are observed.

Applying this result to the authors' experiments, we may note that wear fragments are formed during sliding, and that, whatever their chemical nature, they will have the same effect in hindering the growth of the junctions as had the surface roughness in our experiments. Thus, if fragments are formed during sliding, the drop in friction after a number of cycles is to be expected on physical grounds, whether or not formation of oxide takes place.

E. Rabinowicz

AUTHORS' CLOSURE: The authors [of "Early Stages of Fretting of Copper, Iron & Steel"] did not intend to imply that the decrease in friction coefficient was due entirely to a chemical change (meaning the formation of a lower shear strength compound between the sliding surfaces). The following facts are presented in support of the theory that part of the decrease was a result of physical changes: (1) Specimens of fully oxidized materials, such as Fe_2O_3 and CuO, on which no chemical change occurred, showed a decrease in friction coefficient; (2) In the start of fretting both plowing and reciprocating sliding exist. In such a case a protruding welded fragment plows a furrow in the opposing surface during the first few cycles, but thereafter moves back and forth with less resistance, thus decreasing the friction. This result is confirmed by the occurrence of high initial values of friction in association with large amounts of adhesion and plowing at the start of fretting of several of the material combinations; (3) The number of metallic junctions in the contact area may be decreased by the presence of loose wear fragments. This is closely allied to Dr. Rabinowicz' suggestion that the presence of wear fragments hinders the growth of individual junctions.

D. Godfrey & J. M. Bailey

Practical Lubrication, No. 14

WIRE DRAWING LUBRICANTS

by L. Salz*

Lubrication practices for wire drawing, both ferrous and non-ferrous, are reviewed.

Wire drawing lubrication is a specialized field that is frequently unfamiliar to technologists and engineers concerned with general problems of industrial lubrication. Ask a plant lubrication engineer about the type of maintenance oils or greases required in an industrial machine and you will get an authoritative answer. Ask him about the type lubricant that he would recommend for drawing #10 gauge copper wire and the chances are that his answer will be sketchy. The purpose of this paper is to review the subject of wire drawing lubrication so that those less familiar with this specialized field will have a better understanding of the products available and their respective applications.

WIRE DRAWING PROCEDURE. Wire drawing is a process of reducing the diameter of wire by pulling it through a die or several dies of progressively smaller apertures. This is done either by a so-called "dry," or by a "wet" method of lubrication. The distinction between these two methods lies in whether a solid or liquid lubricant respectively is employed.

In the dry method of lubrication, the lubricant is placed in a box of 1 to 5 pound capacity immediately ahead of the die. The wire passes through the box, picks up some of the lubricant and then enters the die. The dry drawing lubricant may be a granulated soap or granulated soap plus pigment (usually lime) or a grease. The dry drawing method of lubrication is most commonly used on ferrous wire larger than .035" diameter (20 gauge).

The wet method of lubrication is practiced by circulating a liquid lubricant to the wire ahead of the die or by immersing the die in a liquid lubricant bath. Common lubricants for this method of lubrication are aqueous soap-fat solutions, soluble oil emulsions and compounded oils. Ferrous wire smaller than 20 gauge and most non-ferrous wire are drawn by the wet method.

Prior to drawing it is important to remove oxides, scale and other forms of corrosion from the wire if maximum die life is to be obtained. This is generally done by acid pickling. In some cases, especially with ferrous wire, alkaline coatings such as lime are applied to the wire after pickling and washing. The function of the coating is to protect the wire from corrosion during storage and to help pick up the dry drawing lubricant. Considerable attention is being given to the use of mechanical descalers to supplant the removal of scale by acid pickling, but this very attractive alternative has not yet been developed to the point of general acceptance.

FUNCTIONS OF COMPONENTS. When a manufacturer compounds a wire drawing lubricant, each component is added for some specific purpose. Fats, fatty oils and soaps are most commonly used to impart lubricating qualities. These components have the property of strong physical adherence to the wire under conditions of high pressure and minimize friction and wear. Water soluble type soaps are excellent materials for wire drawing formulations because in addition to their lubricating characteristics they function as emulsifiers for fats and fatty oils, rendering these materials water-dispersible. Furthermore, water-soluble soaps lower the surface tension of water, which is the basis for their function as wetting agents and detergents. The water insoluble soaps have higher melting points than the soluble varieties and are, therefore, desirable in dry drawing operations where considerable heat is developed.

The use of lime in dry drawing formulations is to reduce the slipperiness of straight soap and give proper balance to the frictional characteristics required. Water serves as a coolant, being one of the best materials known for the dissipation of heat. The function of mineral oil in a drawing lubricant is to act as a carrier or diluent for the polar compounds and extreme pressure material blended in it and, secondly, to serve as a coolant. Heat resistant solid lubricants, such as graphite, are used where high temperature conditions of operation do not permit the use of fats, oils or soaps. The solid lubricants may also serve along with lime and chalk as pigments in mechanically separating the wire from the die. Chemical type extreme pressure components, such as chlorinated and sulphurized compounds, react with the wire during the drawing operation to form protective chemical coatings which minimize welding and seizure.

The specific compound selected from a group of related materials and the concentration in which it is used is generally determined by the manufacturer's experience in field tests and by cost considerations.

CLASSIFICATION OF WIRE DRAWING LUBRICANTS. The wire drawing lubricants commonly used may be divided into seven categories — dry granulated soaps, soap-fat paste compositions, compounded mineral oils, petroleum greases, soluble oils, graphite compositions and soft metals.

1. **Dry Granulated Soaps.** These soaps are used for dry drawing lubrication. They are employed almost to the exclusion of all other lubricants in drawing of ferrous wire down to #20 gauge (.035") and are sometimes used in initial reductions of aluminum wire.

Two types of dry drawing soaps are commonly manufactured — sodium soaps and calcium soaps. The latter, along with other water-insoluble soaps, are known to the wire industry as "metallic soaps."

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(This is technically a misnomer since soap, including sodium soap, is by definition a metallic salt of a fatty acid.) Aluminum soaps are third in importance in dry drawing lubrication. These soaps are used especially for drawing cold heading wire because they leave a hard non-tacky film on the wire which minimizes sticking of dies in extrusion machines.

The sodium soaps are prepared by saponifying fat, or fatty acid, with caustic soda or soda ash. The fat used is usually tallow or the synthetic hard fats made by the hydrogenation of vegetable or fish oils. The saponification product must be freed of the by-product, glycerine, if fat was the starting point for the manufacture of the soap. It is then dried, removing the water content so completely that the soap is practically anhydrous. The presence of only a small amount of water ruins a soap for dry drawing lubrication. As a final step in the manufacturing process, the dried soap is ground to a convenient particle size; too coarse can result in inadequate lubrication, whereas too fine can be objectionable from soap dust floating in the air and problems of wire tunneling.

The water-insoluble soaps are prepared by reacting water solutions of the metal salt with a sodium soap solution. The insoluble soaps separate as a curd, which is washed free of contaminants, dried and ground.

In those cases where a "leaner" or "less rich" soap is desired, pigments such as lime or chalk may be added as a dry powder either by the manufacturer or the user.

It is to be noted that the sodium soaps are water-soluble but generally less efficient at higher die temperatures than their water-insoluble soap counterparts. The latter have higher melting points and consequently greater resistance to heat and carbonization. Sodium soaps are especially desirable for use where the lubricant must be removed from the wire in a subsequent operation, as in preparation for galvanizing, tinning or lacquering.

2. Soap-Fat Paste Compositions. These materials are generally used for all copper and brass wire and for ferrous wire above 20 gauge. Paste compositions are the conventional materials in use for wet method drawing.

While there are many modifications and variations of the paste type composition, all of them generally contain a water-soluble soap, fatty material and water. The usual range in composition of a typical paste compound is given below:

Type of Material	Example of Component	Concentration range %
Soap	Potassium Stearate	10-65
Fats or Fatty Oils	Tallow	5-50
Unsaponifiable	Mineral Oil	0-15
Fatty Acid	Stearic Acid	0.5-3.0
Diluent	Water	25-40

For copper and brass wire drawing, high fat — low soap compositions are used for the coarser sizes whereas low fat — high soap compositions are formulated for fine wire drawing. The concentration of product to water ranges from approximately 1% for fine wire to 7% for initial reductions of rod. For fine ferrous wire drawing a low soap — high fat composition is used, the concentration being within the limits of 0.5 to 3.0%.

3. Compounded Oils. These products are widely used for drawing aluminum wire of all sizes and are gaining popularity in drawing fine sizes of stainless steel in continuous wet drawing machines. Soap solutions are not generally used for aluminum wire drawing because of corrosion or staining difficulties when the pH is above 8.5.

A compounded oil is a mineral lubricating oil into which fatty material such as lard oil has been incorporated. It may also contain other additives such as sulphurized fats and chlorinated compounds. High viscosity oils (1000 to 2500 Saybolt viscosity at 100 F.) are used on aluminum rod and heavy wire with progressively lower viscosities employed as the wire diameter is reduced. A compounded oil of approximately 100 to 300 Saybolt seconds viscosity at 100 F., is used for fine aluminum or stainless steel wire. Lubricants for the latter grades of wire require extreme pressure compounds to prolong die life. The usual range of fat and additive content for compounded oils is 10 to 30%.

It is to be noted that while the friction reducing and wetting characteristics of compounded oils with respect to metals may be superior to soap-fat solutions, oils are less efficient coolants than water. As a consequence, care must be taken with the use of oils to avoid overheating the dies.

4. Petroleum Greases. Greases are used where extra bright or clean finish on the wire is required, such as for coat hanger wire or welding rod. Grease drawing is accomplished in dry drawing machines simply by using grease in the lubricant box.

WIRE DRAWING LUBRICANT RECOMMENDATION CHART

I. Dry Process	
A. Steel	
1. Subsequent removal of lubricant must be complete, as required in tin or zinc plated wire	Sodium Soap
2. Subsequent removal of lubricant not necessary	Calcium Soap
3. Cold heading wire	Aluminum Soap
4. Extra clean and bright wire	Pigmented Grease or Soap-Fat Compound
B. Copper and Brass	Tallow or High Fat - Low Soap Compound
C. Aluminum	Aluminum Soap
II. Wet Process	
A. Steel	
1. Carbon Steels	1/2-3% solution of High Fat - Low Soap Compound
2 Alloy Steels	100-300 SUS (20-65cs) at 100 F. Compounded Oil containing sulphur, chlorine and fat
B. Copper and Brass	
1 Below 20 gauge - coarse sizes	3-7% solution of High Fat - Low Soap Compound
2. Above 20 gauge - fine sizes	1/2-3% solution of Low Fat - High Soap Compound
C. Aluminum	
1. Below 20 gauge - coarse sizes	1000-2500 SUS (215-540cs) at 100 F., Compounded Oil
2. Above 20 gauge - fine sizes	100-200 SUS (20-45cs) at 100 F. Compounded Oil

A petroleum grease is a mineral lubricating oil that has been gelled by addition of soap. The most common grease in service is "cup grease," which is made from a high titre calcium soap as the gelation agent. The addition of lime to the grease is sometimes practiced to adjust the frictional characteristics for improved results. It is important that the consistency of the grease be heavy enough so that it does not run out of the die box and yet sufficiently soft to prevent it from channeling.

Soap-fat pastes or compounds (without water dilution) are sometimes used for grease drawing, although these materials are not technically greases. In recent years special wire drawing greases have been prepared containing high concentrations of sulphurized and chlorinated extreme pressure materials. These more expensive products are superior to the calcium type cup grease in giving brighter wire and longer die life.

5. Soluble Oils. Soluble oils are occasionally used in place of soap-fat compounds as the drawing lubricant in high speed continuous wet drawing machines because of the relative absence of foaming.

The conventional general purpose soluble oil, characterized by the formation of a milky, opaque emulsion when the oil is added to water, is prepared by adding emulsifiers (mineral oil sulfonates and potassium soaps) to a straight mineral lubricating oil. These soluble oils act as a rust inhibitor to the coolant water with which it is mixed, while providing some lubricating value. Emulsions of general purpose soluble oils do not have any more load carrying capacity than straight mineral oil, consequently are only suited for very light drawing. Where a soluble oil is required for more difficult drawing, a heavy duty type may be used. Heavy duty soluble oils are prepared by adding chemically active or polar compounds to the usual formulation of a general purpose soluble oil.

Soluble oils are used in concentrations ranging from 2 to 10%.

6. Graphite Compositions. When hot drawing of wire is required, the use of graphite as a lubricant is most common. This material is used because of its greater resistance to decomposition by heat as compared with fats, soaps and mineral oil compositions. The type wires that are drawn hot include Tungsten, Rhodium and Iridium, all drawn at 1800 F., and some high speed steels and alloys.

A uniform coating of graphite on the hot wire is obtained by spraying a mixture of graphite and a volatile liquid carrier such as water or kerosene. The liquid assists in spreading the graphite on the wire and is then lost through evaporation from the intense heat.

7. Soft Metals. In the drawing of "tough" wire such as stainless, it is common practice to coat the wire with a softer metal such as lead, copper or tin. These metals have greater ductility than the base material and thereby facilitate the drawing operation.

BENEFITS OF PROPER LUBRICANT SELECTION. A primary objective in any wire mill is to draw the maximum tonnage of wire at lowest operating cost. The profits of the mill and, in some cases, survival of the business will depend upon the degree of efficiency with which the plant can operate.

While the selection of wire drawing lubricants may appear to be of minor consequence to personnel not technically familiar with the wire mill operations, these materials do represent a major factor in achieving maximum production. The use of the proper lubricant for a given set of operating conditions allows for faster drawing speeds, longer uninterrupted production, better looking wire and maximum life of expensive dies.

Lubrication Summarized

HINTS ON BABBITTING PRACTICE, Federated Metals Div., American Smelting & Refining Co.

A large proportion of machinery relies on babbitted bearings for efficient operation. Bearing failures can cause machinery damage and can lead to even greater losses in downtime.

If the basic steps outlined here are carefully followed, downtime will be markedly reduced, repair costs minimized, and production will proceed more smoothly.

Common Causes of Bearing Failures. In the bearing metal itself, the selection of the wrong bearing metal for the job at hand. In the making of bearings, improper bond between the liner and the shell, porosity of the liner, segregation of the constituents in the liner, hard spots which cause scoring of the shaft.

In the installation of bearings, presence of foreign particles, such as dirt or metal chips, causing scoring or seizing of the shaft, insufficient or excessive clearance, misalignment of the shaft.

In the operation and maintenance of bearings, use of improper lubricants, failure to filter foreign particles from lubricants, overloading or over-speeding of the equipment, corrosion due to overheating of lubricant, corrosion due to dilution of lubricant with acidic compounds or water, fatigue caused by high load compressive stresses and high local bonding stresses.

Suggestions for Preventing Bearing Failures. Select the proper bearing metal. The recommendation of the equipment supplier or a reputable manufacturer of bearing alloys should be sought and followed. Generally speaking, tin base babbitts are best for high speed and heavy-duty service . . . lead-base babbitts for medium or low speeds and loads. In making bearings, (melting), make sure that the melting pot is clean, heat the kettle uniformly to prevent segregation, stir the molten metal thoroughly by using a long-handled steel rod with a perforated steel plate attached, control metal temperature with a pyrometer, do not allow the metal to cool while in the pot, or to stand overnight. Segregation will usually occur. Do not add drosses, sweepings, or skimmings. They usually contain detrimental impurities. The safest, and the least expensive procedure is to return all these materials to a reputable smelter for refining.

In bonding, machine the shell surface to a "phonograph" finish, avoid use of lubricant when taking the final cut, degrease in a commercial alkaline cleaner held

(Continued on page 219)

LIMITING BULK FLUID TEMPERATURES FOR EFFECTIVE BOUNDARY LUBRICATION BY SYNTHETIC LUBRICANTS

by S. F. Murray, R. L. Johnson & E. E. Bisson*

A study was made of the effect of high bulk lubricant temperatures on the boundary lubricating effectiveness of various types of synthetic fluids. It was found that synthetics were generally effective lubricants at higher temperatures than comparable petroleums. High temperature lubricating ability can be associated with viscosity grade within a given class of lubricant. The failure temperatures indicated in these experiments are not necessarily identical to the bulk lubricant temperatures which are usable in practical cases. Lower temperature limits may result from chemical effects such as decomposition, corrosion and fluid oxidation while higher temperatures may be permitted in such applications as bearings, where time at temperature is of short duration.

The general trend of temperatures in aircraft gas turbine engines has been steadily upward for the past few years and will undoubtedly continue to rise. As discussed in detail in Refs. 1 thru 6, synthetic lubricants seem to show the most promise of operation at elevated temperature levels. While some data on the friction properties, under boundary lubrication conditions, of synthetic lubricants are available (Refs. 1, 7, 8 and 9), very little data are available on the boundary lubricating characteristics of these synthetic fluids at higher temperatures. Some data showing the effect of temperature on boundary lubrication with polar organic compounds (non-synthetic lubricants) are reported in Ref. 10.

In order to supplement available data on high temperature lubrication, a study was made at the NACA Lewis laboratory to determine the boundary friction characteristics of steel specimens lubricated at temperatures up to about 600 F. by several classes of lubricants, both compounded and uncompounded. The investigation was performed with a kinetic friction apparatus employing steel specimens completely submerged in the fluid under investigation. The results of this investigation are reported in more detail in Ref. 11.

The following companies cooperated in furnishing material for this investigation: Rohm and Haas Co., Carbide & Carbon Chemicals Co., Victor Chemicals Co., California Research Corp., Oronite Chemical Co. and The Standard Oil Development Co. Also, samples of materials compounded by Pennsylvania State College Petroleum Refining Laboratory and others were provided by the Air Force Wright Air Development Center Materials Laboratory. The cooperation of these organizations is gratefully acknowledged.

APPARATUS, PROCEDURE & EXPERIMENTAL FLUIDS. The apparatus used is described in Ref. 9 and is shown schematically in Fig. 1. The basic elements are the rotating mild-steel disk specimen (hardness, Rockwell A-50; 2.5 in. diam.) and the cylindrical, hardened (hardness, Rockwell C-60), SAE 1095 steel rider specimen with a hemispherical (3/16 in. rad.) contact tip. The method of finishing and cleaning specimens is reported in detail in Ref. 11.

Experiments were conducted at a sliding velocity of 120 feet per minute with a load of 1000 grams (initial Hertz surface stress of 149,000 lb/sq in.). For each test, 440 cubic centimeters of fluid and a new set of specimens were used. The apparatus was started simultaneously with the application of heat, and friction readings were taken at 25 C. (45 F.) intervals or more often if necessary. The average time required to raise the temperature of the fluid from 100 F. to 500 F. was 55 minutes and did not vary by more than 5 minutes for any fluid tested. After the runs in which failure occurred, visible surface damage was observed. The temperature failure points were reproducible to within $\pm 15°$ F. The friction coefficient, was generally reproducible to within ± 0.02.

The experimental fluids and their properties are listed in Table I.

The compounded fluids PRL 3161, PRL 3312, and PRL 3313 are described in more detail in Ref. 12. These three materials use di(2-ethylhexyl) sebacate as the base stock. PRL 3161 contains an oxidation inhibitor (phenothiazine), a viscosity-index improver (methacrylate polymer) and an anti-wear additive (tricresyl phosphate). PRL 3312 is 3161 without the viscosity-index improver but containing a chemically active additive which is believed to be lauryl acid phosphate (Ref. 12). PRL 3313 is 3161 with an additional 5 percent viscosity-index improver; PRL 3313 also contains a chemically active additive believed to be lauryl acid phosphate.

In the experiments the fluids were contained in a pyrex beaker which was heated directly on a hot plate as shown in Fig. 1.

RESULTS AND DISCUSSION. During the course of each experiment, the following observations were considered most important as indications of the lubrication failure: (1) Onset of instability or a marked increase in the friction force, (2) Surface failure (incipient or mass) of the sliding specimen, (3) Decomposition of the bulk lubricant.

Preliminary wear tests (described in Ref. 11),

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conducted with some of these lubricants, showed that either unstable friction values or an increase in the coefficient of friction was accompanied by a sharp increase in the rate of wear. Fig. 2 presents data from one of a series of experiments designed to correlate wear (qualitative) with friction instability as it was encountered in most of the experiments with increasing bulk lubricant temperatures. No significance should be attached to absolute wear values; the trend of the curve was, however, reproducible and indicates that there is a definite relation between instability or a marked increase in friction and a considerable change in the rate of wear.

The results of the experiments described herein are presented in Figs. 3 to 6 and also in Table I, in which are summarized the pertinent observations on each fluid with respect to failure temperature, initial friction coefficients and surface appearance. Figs. 3 to 6 show the effect of temperature on friction of steel specimens boundary lubricated with the various fluids.

COMPOUNDED FLUIDS. Petroleum Oils. Results for a typical petroleum base stock, MIL-0-6081a (grade 1010), which is currently in use as a gas-turbine engine lubricant are shown in Fig. 3(a). The frictional values indicate sudden lubrication failure just below 300 F.

One of the generally accepted hypotheses explaining effective lubrication with petroleum involves the presence of polar contaminants (Ref. 13, p. 2) and the subsequent chemisorption of these contaminants on the surface. The data of Fig. 3(a) present results of a hydrocarbon lubricant (cetane) without and with a polar material (stearic acid), respectively.

The cetane was purified by percolation through an adsorption column as described in Ref. 14. The occurrence of immediate, incipient surface failure and the high friction values were characteristic of pure cetane containing no polar materials. At 257 F., the surface damage became so severe that complete seizure of the specimens took place and there was no further relative sliding.

The data for a purified sample of cetane, containing 1 percent by weight of stearic acid, are shown in Fig. 3(a). Failure of this fluid occurred at approximately 315 F. The point of failure of the bulk solution of stearic acid in cetane agrees quite well with the value obtained by Bowden (Ref. 10, p. 203) of about 295 F. for mild-steel surfaces lubricated with thin films of stearic acid. As Ref. 10 points out, this temperature coincides with the softening point of the iron soap which is formed by the reaction of stearic acid with the steel surfaces.

Synthetics. Several compounded diester lubricants were studied that were believed to have di (2-ethylhexyl) sebacate as the base stock. The data are presented in Figs. 3(b), (d), (e) and (f) and show that the various fluids have different characteristics as a result of the amounts and types of additives.

Inconsistent results were obtained with different batches of the commerical fluid meeting MIL-L-7808 specification. The data reported in Fig. 3(f) show that the run was stopped because of heavy vaporization of the fluid which (in several runs) began at 380 F. and continued until the run was terminated at 430 F. With an earlier batch having the same commercial designation, vaporization was less severe but was noted to begin at 380 F. The running with the first batch produced incipient lubrication failure at 420 F., however, in runs with the second batch used to obtain the data reported herein, no well defined lubrication failure was observed at the maximum temperature of 430 F.

The polypropylene glycol did not show a lubrication failure temperature, Fig. 3(c). It did, however, start to decompose at a temperature of 440 F. and very heavy vapors were coming from the lubricant container; in consequence, no data were obtained at higher temperatures.

UNCOMPOUNDED FLUIDS. Diesters. The results obtained with the uncompounded diesters of Table I are shown in Figs. 4(a) to (c). Di(2-ethylhexyl) sebacate and di(2-ethylhexyl) adipate gave similar results, both showing incipient surface failure at approximately 400 F. and mass surface failure at approximately 500 F. The di "isooctyl" adipate also showed incipient surface failure at approximately 400 F., but showed mass surface failure at 560 F.

Separate solutions of 5 percent tricresyl phosphate in di(2-ethylhexyl) sebacate, 0.5 percent phenothiazine in di(2-ethylhexyl) sebacate, and 3.8 percent methacrylate polymer viscosity-index improver in di(2-ethylhexyl) sebacate were prepared, and the results are shown in Fig. 5. These results indicate that the increased lubricating effectiveness of the compounded diester over that of the di(2-ethylhexyl) sebacate at higher temperatures is a function of the tricresyl phosphate and is not dependent on the presence of the oxidation inhibitor or the viscosity-index improver. The curves show that instability starts at essentially the same temperature for all except the solution of tricresyl phosphate in di(2-ethylhexyl) sebacate.

The chemisorption hypothesis suggested for petroleum is also considered to be applicable for diesters. Minute amounts of free fatty acid and alcohol are formed from decomposition of diesters

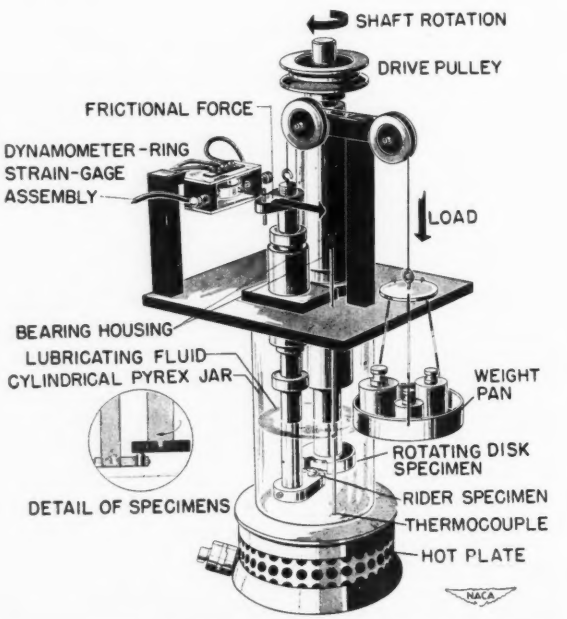

Fig. 1 Schematic diagram of friction apparatus for studying boundary lubrication by bulk lubricants.

either by hydrolysis (Ref. 10, p. 215) or by high temperatures. Formation of free acid could be followed, as in the case of stearic acid, by a reaction between the free acid and the metallic surface (via the metal oxide) to form a metallic soap film, which would provide effective lubrication. This hypothesis was supported by experiments reported in Ref. 1 showing that a diester would not lubricate nonreactive surfaces. The data of Ref. 15 further support this viewpoint in showing definite chemical attack of steel surfaces by esters; these studies were made by means of radioactive tracer methods. To further establish the validity of this hypothesis and to resolve its application to lubrication at high temperatures, the iron soap of sebacic acid was studied.

Since Bowden and Tabor (Ref. 10) have previously shown that the temperature failure point of iron stearate films corresponds to the softening point of this soap, an attempt was made to apply this criterion to the iron sebacate soap. When a small amount of the iron sebacate soap powder was heated on a melting-point apparatus under microscopic observation, decomposition was detected at temperatures above 446 F; however, no apparent softening or melting point was detected. There was no visible change in appearance of the samples at temperatures below 446 F. At 446 F., the powder began to turn slightly darker, and at 500 F. complete decomposition by charring had taken place.

Refs. 10 (p. 211) and 16 (pp. 98-99) show that oxides are necessary for the formation of metallic soap films. In these experiments, if the iron oxide film is present, the corresponding soap film would be formed and would be effective (for lubrication) to either its melting point (Ref. 10, p. 210) or to its decomposition point. On breakdown of the soap film, the oxide film makes more of a direct contribution to the lubrication mechanism. The type of

Fluid	Viscosity, centistokes at 100° F	Viscosity, centistokes at 210° F	A.S.T.M. pour point, °F	C.O.C. flash point, °F	Temperature for incipient failure	Initial friction coefficient	Surface appearance after runs (a)
COMPOUNDED FLUIDS							
Petroleum, MIL-0-6081A (grade 1010)	9.95	2.47	≤ -70	300	293	0.12	MSF
Diesters (using di (2-ethylhexyl) sebacate as base stock)							
PRL 3161[b]	20.8	5.3	< -75	450	505	0.10	MSF
PRL 3312[b]	13.02	3.38	-70	440	415	.10	ISF
PRL 3313[b]	41.78	11.63	-70	420	450	.12	ISF
Commercial fluid meeting MIL-L-7808 specification	14.23	3.64	-70	425	420 (c)	.11	ISF
Polypropylene glycol	13.55	3.31	-70	380	0.09 No lubrication failure - fluid decomposed at 440° F		
UNCOMPOUNDED FLUIDS							
Petroleum, cetane	4.64 (at 22° C)	-----			75	0.55	MSF
Diesters							
Di (2-ethylhexyl)adipate	8.2	2.34	-94	395	392	0.12	MSF
Di (2-ethylhexyl) sebacate	12.78	3.32	< -70	440	410	.11	MSF
Diisooctyl adipate	10.13	2.83	-103	408	392	.11	MSF
Polyalkylene glycols (designated by viscosity at 100° F)							
Water soluble							
8.9 centistokes[d]	8.9	2.4	-85	260	288	0.11	ISF
41 centistokes[d]	41	8.2	-45	410	349	.11	ISF
143 centistokes[d]	143	26.2	-30	430	437	.09	ISF
762 centistokes[d]	762	120	-20	440	501	.12	ISF
Water insoluble							
7.4 centistokes[d,e]	8	2.52	< -70	270	423	.12	ISF to MSF
Phosphonate							
Dioctyl isooctene phosphonate	12.22	2.77	-90	---	None	0.13	EBL
Silicate							
Tetra (2-ethylhexyl) silicate	6.8	2.47	<-100	395	None	0.13	EBL

[a] MSF - Mass surface failure, including violent welding.
ISF - Incipient surface failure - based on friction instability.
EBL - Effective boundary lubrication.

[b] Detailed identification in reference 12.

[c] No incipient failure was observed with a second batch of this fluid but the tests were terminated because of excessive vaporization at 430°. See text.

[d] Manufacturers data.

[e] Contains oxidation inhibitor only.

Table I Experimental fluids and their lubricating effectiveness.

oxide (Fe_2O_3 or Fe_3O_4) would determine the effectiveness of lubrication under these conditions. Since experiments at this laboratory have shown that heating a mixture of stearic acid and Fe_2O_3 reduces the Fe_2O_3 to Fe_3O_4, a similar result might be expected with the chemisorbed iron sebacate reducing the iron oxides, present on steel surfaces, to Fe_3O_4. The data of Ref. 17 show that Fe_3O_4 is an effective lubricant from the standpoint of preventing surface welding.

The mechanism of lubrication by the soap film (or, on partial breakdown of the soap film, by the combined soap film and oxide film) could explain the fact that failure does not occur abruptly as the temperature is increased. At a temperature corresponding to the failure point of the oil, oxidation of the lubricant itself may become so rapid that it takes up the available oxygen (Ref. 18) and makes it impossible for an effective oxide film to be maintained at the sliding surfaces and failure would therefore result.

Polyalkylene glycols. Next, a series of fluids designated chemically as polyalkylene glycols and their derivatives was run; the results are shown in Fig. 4. The first fluid is water-soluble and has a viscosity of 8.9 centistokes at 100 F. It showed (Fig. 4(d)) unstable friction coefficient values above 290 F., indicating that lubrication was continually failing and recovering. A final point of failure without further recovery was not obtained for this lubricant. The next oil was a water-insoluble polyalkylene glycol with a viscosity of 7.4 centistokes at 100 F. The results (Fig. 4(e)) indicate that it possesses better lubricating properties, at intermediate temperatures, than the water-soluble fluid.

In Fig. 6 are shown the frictional values for a series of water-soluble polyalkylene glycol fluids that vary in viscosity from 8.9 to 762 centistokes at 100 F. Although the coefficient of friction obtained below 212 F. does not differ significantly for any member of the series, the results obtained at higher temperatures show a definite relation to some property commonly associated with viscosity grade. Fluids of higher viscosity have greater chain length. The 8.9 centistoke fluid shows instability in friction values at 290 F., the 41 centistoke fluid at 360 F., the 143 centistoke fluid at 437 F.; and the 762 centistoke fluid at 501 F.

The data of Fig. 6 show that, with this apparatus, there is no significant hydrodynamic component; this fact is shown by the lack of difference in friction coefficient between fluids of markedly different viscosities (from 8.9 to 762 centistokes at 100 F.). This result holds for all temperatures up to 290 F. (which is the temperature for lubrication failure of the 8.9 centistoke fluid); above this temperature, friction coefficient of the various fluids is influenced by lubrication failure.

In the process of decomposition, the polyalkylene glycols will form compounds (Ref. 19, pp. 361-366) which could react with ferrous surfaces to form soap films; these soap films would increase the lubricating effectiveness of the bulk fluid at high temperatures.

Esters of inorganic acids. The next class of compounds studied were esters of inorganic acids, the phosphonates and the silicates. The first fluid, dioctyl isooctene phosphonate (Fig. 4(f)), showed no lubrication distress throughout the entire temperature range (to 572 F.). At this temperature, the fluid refluxed violently, decomposed, and left a reddish-brown gel as a residue. The wear track showed no damage and very slight wear, but the surface of the steel specimens appeared to be etched

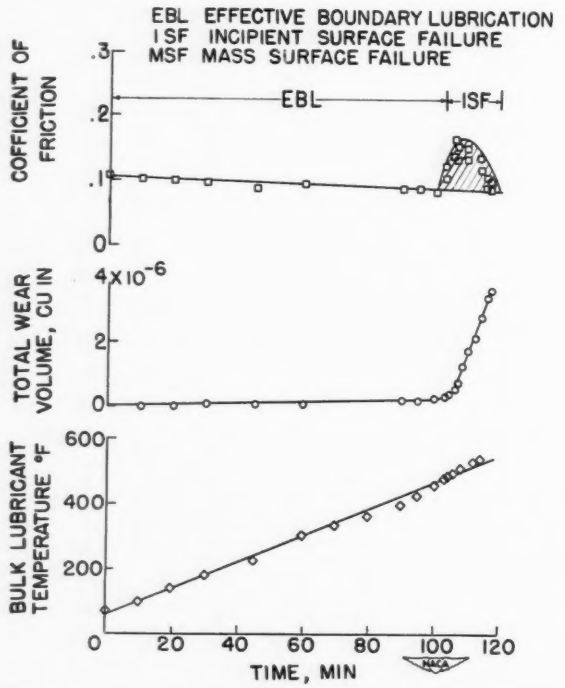

Fig. 2 Relation between unstable friction (cross-hatched area) and wear for typical diester lubricant at increasing bulk temperatures. 1000 grams; 120 feet per minute.

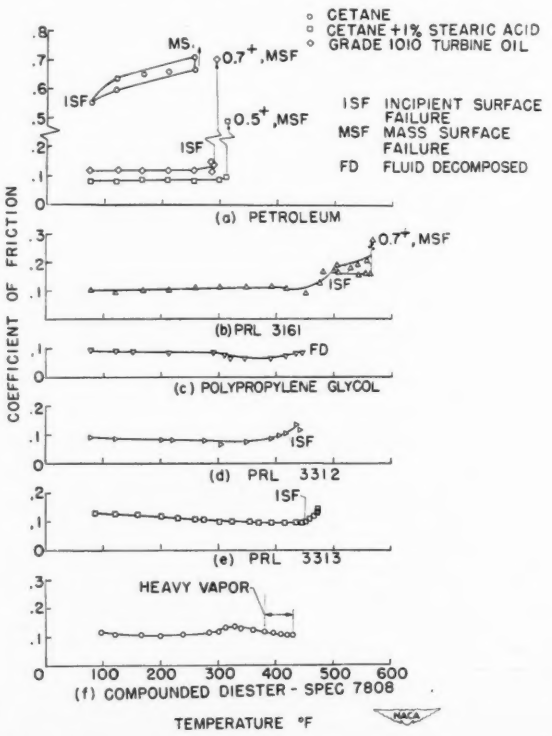

Fig. 3 Compounded fluids.

as if by acid wherever contact with the fluid had taken place. Chemical attack of the surfaces at high temperatures is apparently a logical explanation for the lubricating effectiveness of these fluids.

The results for the silicate ester are shown in Fig. 4(g). This fluid was reported by the manufacturer to be subject to decomposition (in air) at temperatures above 500 F. and was therefore tested only to about 520 F. No signs of lubrication failure could be detected; the wear track showed no surface damage and extremely low wear, as was the case with the phosphonate ester. A separate experiment was made (Ref. 11) with this same fluid containing an oxidation inhibitor, phenyl-a-naphthylamine; no discernible effect on the friction results were noted. When heated in a beaker in air, these fluids were found experimentally to decompose above 540 F., a result which was also independent of the presence of an oxidation inhibitor. There was no visible evidence of etching of the steel specimens used in the experiments with the silicate esters. At this time there is no explanation for the lubricating effectiveness of the silicate esters at high temperatures.

Miscellaneous fluids. An experiment was made with a dimethyl polysiloxane which had a viscosity of 50 centistokes at 25 C. (77 F.). Friction coefficient was high (0.3 to 0.4) throughout the test, and mass surface failure and appreciable wear occurred at all temperatures.

The hypothesis has been advanced (Ref. 9) that the addition of a solvent to the silicone fluid will result in improved lubricating effectiveness. Some preliminary results were obtained with a fluid consisting of 33 percent by volume di(2-ethylhexyl) sebacate in a silicone. A degree of incipient failure was encountered at 307 F., although no point of mass failure was observed in the experiment. Observation of the specimens indicated that, even after lubrication failure occurred, surface damage and wear were not as severe as would be the case with the silicone lubricant alone.

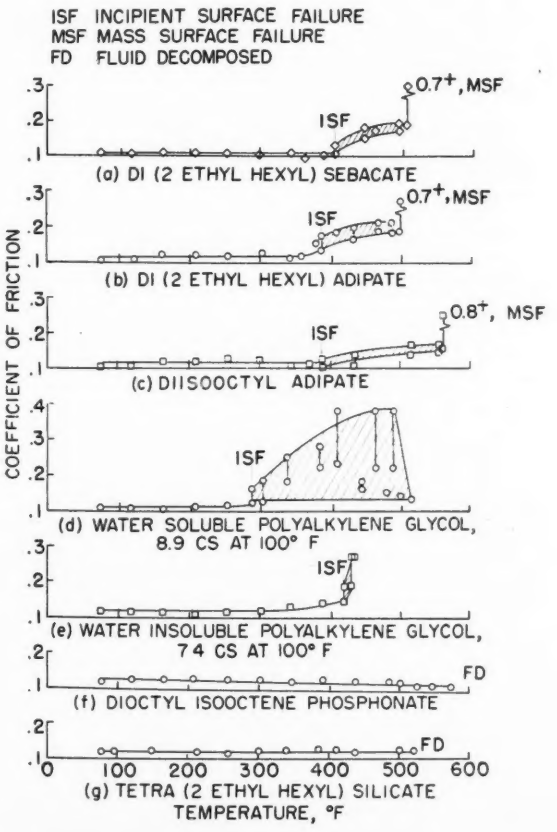
ISF INCIPIENT SURFACE FAILURE
MSF MASS SURFACE FAILURE
FD FLUID DECOMPOSED
COEFFICIENT OF FRICTION
0.7+, MSF
ISF
(a) DI (2 ETHYL HEXYL) SEBACATE
(b) DI (2 ETHYL HEXYL) ADIPATE
0.8+, MSF
(c) DIISOOCTYL ADIPATE
(d) WATER SOLUBLE POLYALKYLENE GLYCOL, 8.9 CS AT 100° F
(e) WATER INSOLUBLE POLYALKYLENE GLYCOL, 74 CS AT 100° F
FD
(f) DIOCTYL ISOOCTENE PHOSPHONATE
(g) TETRA (2 ETHYL HEXYL) SILICATE
TEMPERATURE, °F

Fig. 4 Uncompounded synthetic fluids.

CONCLUDING REMARKS. The results reported herein, are relative and apply only to the conditions of load, speed and for the method of laboratory experimentation used herein.

The superior lubricating properties, at high temperatures, of synthetic lubricants over petroleum lubricants are clearly demonstrated for these conditions. Distinguishing between the various synthetic fluids is not as simple. In the case of the phosphonate and silicate fluids, no lubrication failure is observed in a region approaching the point at which the lubricant itself actually decomposes. It is speculated that esters, and possibly other synthetics, lubricate because minute amounts of contaminating free acids become chemisorbed on the lubricated metals. Lubrication failure may occur by (1) failure of the chemisorbed metal soap film (by melting or decomposition), or (2) failure of the lubricant to maintain the metal soap or oxide films, or both, on the surface as the lubricant decomposes. High temperature stability, in turn, is influenced by structural changes in the molecule.

For the diesters and polyalkylene glycols, an attempt was made to determine whether all the fluids showed a common viscosity at their individual failure temperatures; the viscosity values were, however, appreciably different. Values of density at the failure temperature of each individual fluid were also appreciably different, as were the failure temperatures of those fluids that had approximately the same flash points. It is therefore believed that the lubrication failure of these synthetic fluids cannot be related specifically either to viscosity, to

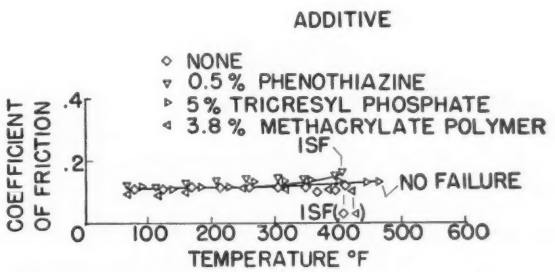

Fig. 5 Effect of additives in di(2-ethylhexyl) sebacate.

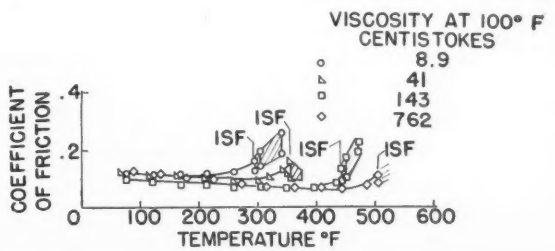

Fig. 6 Effect of viscosity: a series of water-soluble polyalklene glycols.

density of the fluid (at temperature of failure), or to flash point.

The limiting temperatures at which lubrication failure occurred are not necessarily the bulk lubricant temperatures to which the lubricants can be utilized in practical cases. Factors other than lubrication failure may become the limitation; for example, chemical effects such as decomposition, corrosion and fluid oxidation may limit the use temperature to values lower than the temperatures for incipient surface failure shown in Figs. 3 to 6. Since the chemical effects are time-temperature dependent, it may, however, be possible to use these lubricants up to the lubrication failure temperature for "short time" applications.

The maximum allowable bearing temperatures may be substantially above the bulk oil temperature limits indicated herein. In bearing lubrication, the oil is normally supplied at low "oil-in" temperatures and the oil residence (dwell) time may not be sufficient so that high bulk oil temperatures are obtained. In some rolling contact bearing experiments with low "oil-in" temperatures, adequate lubrication has been obtained with bearing temperatures approximately 200 F. higher than the temperature reported herein for incipient surface failure with the same lubricant.

Studies reported in Ref. 1 on the lubricating effectiveness of many of these fluids at high sliding velocities showed that, with some exceptions, there is a general correlation between the maximum temperature for effective boundary lubrication and the limiting sliding velocity for effective boundary lubrication.

Some of these data show that considerable gain (up to 200 F.) in high temperature lubrication limits for liquids can be made by relaxing the low temperature specification, that is, by use of lubricants of higher viscosity. This relaxation in low temperature specifications, however, requires a re-evaluation of both low and high temperature requirements.

Silicate and phosphonate esters showed no lubrication failure at temperatures approaching those at which the fluids decomposed. The silicate esters showed no visible etching of the steel specimens, however, the phosphonate esters caused corrosive etching of the steel specimens under these same conditions. It may be possible to use lubricants which show corrosive tendencies at high temperatures in the "short time" engine; where long service life is not important it may be possible to tolerate some corrosion provided effective lubrication is maintained.

Tests were made of di(2-ethylhexyl) sebacate with various additives. The results showed that the increased lubricating effectiveness, at higher temperatures, of the compounded diester over that of di(2-ethylhexyl) sebacate alone is a function of the tricresyl phosphate and is not dependent on the presence of the oxidation inhibitor or the viscosity-index improver.

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ASME-ASLE

CONFERENCE ON LUBRICATION

October 18 & 19, 1954

Lord Baltmiore Hotel **Baltimore, Md.**

A TENTATIVE GLOSSARY OF LUBRICATION TERMS

compiled by the ASLE Educational Committee

Five years ago the Educational Committee of ASLE undertook the preparation of a glossary of lubrication terms with the idea of establishing standard definitions for Educational Committee publications. After compiling a list of those terms which it was felt should be included and after referring to various glossaries and definitions which were available, a preliminary glossary was prepared and distributed to the members of the Committee in 1950. This was thoroughly discussed and subsequently many of the definitions were changed, some were added, others were dropped and a revised glossary presented in 1952. The process was repeated in 1953 and now, again, in 1954. In fact, there is danger of its becoming an annual affair if steps are not taken to stop somewhere along the line and say this is it. At the meeting of the Committee in April, 1954, it was decided that the project had reached the stage where little would be gained by further delay in publication. It is accordingly presented here in tentative form, with the idea that its appearance will engender a more thorough discussion as to its suitability and completeness.

In deciding what terms should be included in such a glossary and how they should be defined, it is first necessary to establish the level on which it is to be written. After considering this problem quite thoroughly and after preparing both rigorous, technical and loose, non-technical definitions of many terms to get an idea as to what glossaries based on either level would be like, it was decided that the present glossary would be prepared on the assumption that the reader had a familiarity with high school mathematics, physics and chemistry.

In addition to this premise, the following principles were applied:

1. Terms which are included must fall in either of three categories: (a) Those peculiar to the subject of Lubrication; (b) Those which have a meaning in Lubrication which is different from their usual meaning: (c) Those which would ordinarily not be familiar to a person familiar with high school mathematics, physics and chemistry.

2. Each term was defined as accurately and as simply as possible, consistent with its strict meaning and its accepted usage.

3. Care was taken to limit each description to a definition only and to avoid statements of performance.

4. Terms in poor or loose usage were either omitted or described as being in inaccurate use.

5. Abbreviations are not defined in this glossary. These will be covered separately.

ABSOLUTE VISCOSITY, see **VISCOSITY.** A term used interchangeably with viscosity to distinguish it from either kinematic viscosity or commercial viscosity. It is occasionally referred to as dynamic viscosity.

Absolute viscosity and kinematic viscosity are expressed in fundamental units. Commercial viscosity such as Saybolt viscosity is expressed in arbitrary units of time, usually seconds.

ACID. In a restricted sense, any substance containing hydrogen in combination with a non-metal or non-metallic radical and capable of producing hydrogen ions in solution.

ACIDITY. In lubricants, acidity denotes the presence of acid-type constituents whose concentration is usually defined in terms of acid number. The constituents vary in nature and may or may not markedly influence the behavior of the lubricant. (See also **ACID NUMBER.**)

ACID NUMBER. See **STRONG ACID NUMBER.** See **TOTAL ACID NUMBER.**

ADDITIVE. A chemical compound or compounds added to a lubricant for the purpose of imparting new properties or of enhancing those properties which the lubricant already has.

ALKALI. Any substance having basic properties. In a restricted sense it is applied to the hydroxides of ammonium, lithium, potassium and sodium.

ALUMINUM-BASE GREASE. A grease prepared from a lubricating oil and an aluminum soap.

ANHYDROUS. Devoid of water.

ANILINE POINT. As applied to a petroleum product, the lowest temperature at which the product is completely miscible with an equal volume of freshly distilled aniline.

A.P.I. GRAVITY. A gravity scale established by the American Petroleum Institute and in general use in the petroleum industry, the unit being called the "A.P.I. degree". This unit is defined in terms of specific gravity as follows:

$$\text{Degrees A.P.I.} = \frac{141.5}{\text{sp. gr. } 60/60^\circ\text{F.}} - 131.5$$

APPARENT VISCOSITY. A term used in referring to the resistance to flow of fluids whose viscosity varies with the rate of shear. It can be evaluated in a capillary type instrument where it is defined as the shear stress at the capillary wall divided by the mean rate of shear as computed from the Poiseuille equation. It is expressed in fundamental viscosity units at a given rate of shear.

ASPHALTIC. Essentially composed of or similar to asphalt. Frequently applied to lubricating oils derived from crudes which contain asphalt.

AXIAL-LOAD BEARING. A bearing in which the load acts in the direction of the axis of rotation.

BALL BEARING. A rolling type bearing containing rolling elements in the form of balls.

BARIUM BASE GREASE. A grease prepared from lubricating oil and a barium soap.

BASE. In a restricted sense, a compound which yields hydroxyl ions in aqueous solution, or a compound which reacts with an acid to form a salt and water.

BEARING. A support or guide by means of which a moving part is positioned with respect to the other parts of a mechanism.

BLACK OILS. Any dark colored lubricating oil which is

used for the lubrication of machine parts under exposed conditions.

BLEEDING. The tendency of a liquid component to separate from a liquid-solid or liquid-semi-solid mixture; as an oil from a grease.

BLOCK GREASE. Generally, a grease of high dropping point which, under normal temperatures is firm to the touch and can be handled in block or stick form.

BLOCK PENETRATION. The penetration at 77F. of a grease which is sufficiently hard to hold its shape. (ASTM Designation D 217-48.)

BLOWN OILS. Fatty oils, such as rapeseed, whale or various fish oils which are artificially thickened by blowing a current of air through them.

BODY. A loose term, usually used to designate viscosity or consistency.

BOMB. In lubrication terminology, a closed container used for conducting tests under elevated pressures.

BONE OIL. Fatty oil obtained by the dry distillation of bones.

BOUNDARY LUBRICATION. A condition of lubrication in which the friction between two surfaces in relative motion is determined by the properties of the surfaces and by the properties of the lubricant other than viscosity.

BRIGHT STOCK. A term referring to high viscosity lubricating oils which have been refined to make them clear products of good color.

BY-PASS FILTRATION. A system of filtration in which only a portion of the total flow of a circulating fluid system passes through a filter at any instant or in which a filter having its own circulating pump operates in parallel to the main flow.

CAPILLARITY. A property of a solid-liquid system manifested by the tendency of the liquid in contact with the solid to rise above or fall below the level of the surrounding liquid; as in a small bore (capillary) tube.

CARBON RESIDUE. The residue remaining after the evaporation of a sample of mineral oil under specified conditions.

Ramsbottom method. See ASTM designation D 524-42.

Conradson method. See ASTM designation D 189-46 (this method superseded by Ramsbottom method).

CENTIPOISE (cp.). A unit of absolute viscosity. 1 centipoise = .01 poise.

CENTISTOKE (cstk.). A unit of kinematic viscosity. 1 centistoke = .01 stoke.

CENTRALIZED LUBRICATION. A system of lubrication in which the lubricant or lubricants for the bearing surfaces of a machine or group of machines are supplied from a central location.

CETANE NUMBER. A number which expresses the ignition quality of a diesel fuel and equal to the percentage by volume of cetane ($C_{16}H_{34}$) in a blend with methyl naphthalene, which blend has the same ignition preformances as the test fuel.

C.F.R. ENGINE. A standard engine employed to determine the octane numbers of motor fuels. Developed by the Cooperative Fuel Research Committee.

CHAIN LUBRICATION. A system of lubrication in which a continuous chain is used in a manner similar to an oil ring.

CHEMICAL STABILITY. The tendency of a substance or mixture to resist chemical change.

CIRCULATING LUBRICATION. A system of lubrication in which the lubricant, after having passed through a bearing or group of bearings, is recirculated by means of a pump.

CLEARANCE BEARING. A journal bearing in which the radius of the bearing surface is greater than the radius of the journal surface.

CLEVELAND OPEN CUP. See **FLASH POINT, FIRE POINT.**

COASTAL OIL. Naphthenic type petroleum oil refined from crudes obtained from regions near the Gulf and Pacific Coasts.

COEFFICIENT OF FRICTION. The number obtained by dividing the friction force resisting motion between two bodies by the normal force pressing the bodies together.

COHESION. That property of a substance which causes it to resist being pulled apart by mechanical means.

COLD TEST. As referred to an oil, a test by which the pour point is determined.

COMPOUND. (1) Chemically speaking, a distinct substance formed by the combination of two or more elements in definite proportions by weight, and possessing physical and chemical properties different from those of the combining elements.

(2) In petroleum processing, generally connotes fatty oils and similar materials foreign to petroleum, added to lubricants to impart special properties.

COMPOUNDED OIL. A petroleum oil to which has been added animal or vegetable oil, or other substances.

CONSISTENCY. The degree to which a semi-solid material such as grease resists deformation. (See ASTM designation D 217-48.)

Sometimes used qualitatively to denote viscosity of liquids.

COOLANT. A fluid used to remove heat. See **CUTTING FLUID.**

CORROSION. Destruction of a metal by chemical or electrochemical reaction with its environment. (Corrosion Handbook.)

CRACKING. The process whereby large molecules are broken down by the application of heat and pressure to form smaller molecules.

CUP GREASE. A grease, generally lime base, suitable for use in grease cups.

CUTTING FLUID. Any fluid applied to a cutting tool to assist in the cutting operation by cooling, lubricating or other means.

CUTTING OIL. A cutting fluid composed either entirely of oil, or oil and additives which are usually oil soluble.

DEGRAS. An animal oil extracted from the skin or wool of sheep.

DEMULSIBILITY. The ability of a fluid which is insoluble in water to separate from water with which it may be mixed in the form of an emulsion. The higher the demulsibility rating, the more rapidly the fluid separates from water. Demulsibility is sometimes expressed as the rate, in cubic centimeters per hour at which a fluid settles out of an emulsion. (See **STEAM EMULSION NUMBER.**)

DENSITY. The mass of a unit volume of a substance. Its numerical value varies with the units used.

DETERGENT. In lubrication, either an additive or a compounded lubricant having the property of keeping insoluble matter in suspension thus preventing its deposition where it would be harmful. A detergent may also redisperse deposits already formed.

DIELECTRIC STRENGTH. A measure of the ability of an insulating material to withstand electric stress (voltage) without failure. Fluids with high dielectric strength (usually expressed in volts or kilovolts) are good electrical insulators. (ASTM Designation D 877-49.)

DISPERSANT. In lubrication, a term usually used interchangeably with detergent.

DROP FEED LUBRICATION. A system of lubrication in which the lubricant is supplied to the bearing surfaces in the form of drops at regular intervals.

DROPPING POINT (OF GREASE). The temperature at which a grease passes from a semi-solid to a liquid state under specified test conditions (ASTM Designation D 566-42).

DYNAMIC (KINETIC) FRICTION. The friction between two surfaces in relative motion. Sometimes called sliding friction or the friction of motion.

DYNAMIC VISCOSITY. See **ABSOLUTE VISCOSITY.**

EMULSIBILITY. The ability of a non-water soluble fluid to form an emulsion with water.

EMULSION. A mechanical mixture of two insoluble liquids as oil and water.

E.P. (EXTREME PRESSURE) LUBRICANTS. Lubricants which impart to rubbing surfaces the ability of carrying appreciably greater loads than would be possible with ordinary lubricants without excessive wear or damage.

FAT. Originally, a naturally occurring compound of fatty acid and glycerine.

Fats can be of animal or vegetable materials or can be made synthetically.

FATTY ACID. An organic acid of aliphatic structure originally derived from fats and fatty oils.

FATTY OIL. A fat which is liquid at room temperature.

FIBER GREASE. Grease having a distinctly fibrous structure which is noticeable when a sample of the grease is pulled apart. Greases having this fibrous structure tend to resist being thrown off gears and out of bearings.

FILLER. Any substance such at talc, mica or various powders, which is added to a grease to increase its weight or consistency.

FILTER. Any device or porous substance used as a strainer for cleaning fluids by removing suspended matter.

FIRE POINT (CLEVELAND OPEN CUP). The temperature to which a combustible liquid must be heated so that the released vapor will burn continuously when ignited under specified conditions (ASTM Designation D 92-64).

FITTED BEARING. A partial journal bearing in which the radius of the bearing surface is the same as the radius of the journal surface.

FIXED OIL. A term frequently used to describe an oil which is difficult to distill without decomposition. Generally applied to fatty oils.

FIXED PAD BEARING. An axial or radial load type bearing equipped with fixed pads (or lands), the surface of the lands being so contoured as to promote the establishment of a hydrodynamic film.

FLASH POINT (CLEVELAND OPEN CUP). The temperature to which a combustible liquid must be heated to give off sufficient vapor to form momentarily a flammable mixture with air when a small flame is applied under specified conditions. (ASTM Designation D 92-46.)

FLEXURE PIVOT. A type of bearing for limited movement in which the moving parts are guided by the flexure of elastic members rather than by rolling or sliding surfaces.

FLUID. A general classification including liquids and gases.

FLUID FRICTION. Friction due to the viscosity of fluids.

FORCE FEED LUBRICATION. A system of lubrication in which the lubricant is supplied to the bearing under pressure.

FORM OIL. An oil used to lubricate wooden or metal concrete forms in order to keep cement from sticking to them.

FRETTING. Wear phenomena taking place between two surfaces having oscillatory relative motion of small amplitude.

FRETTING CORROSION. Corrosion which results from fretting. Sometimes also called friction oxidation.

FRICTION. The resisting force encountered at the common boundary between two bodies when, under the action of an external force, one body moves or tends to move relative to the surface of the other.

FULL FLOW FILTRATION. A system of filtration in which the total flow of a circulating fluid system passes through a filter.

FUNK TEST. A test used for determining the oxidation resistance of turbine oils. The test is now seldom used.

GAS OIL. A liquid petroleum distillate having a viscosity intermediate between that of kerosene and lubricating oil.

GRAPHITE. A crystalline form of carbon having a laminar structure. It may be of natural or synthetic origin.

GRAVITY. See **SPECIFIC GRAVITY, API GRAVITY.**

GREASE. A lubricant composed of an oil or oils thickened with a soap, soaps or other thickener to a semi-solid or solid consistency.

GUM. A rubber-like, sticky deposit black or dark brown in color, which results from the oxidation of lubricating oils or from unstable constituents in gasoline which deposit during storage or use.

HEAVY DUTY OILS. A term designating a type of oil having the oxidation stability, bearing corrosion preventive properties, and detergent dispersant characteristics necessary to make it generally suitable for use in both high speed diesel and gasoline engines under heavy-duty service conditions. (SAE Handbook)

HYDRAULIC OIL. An oil specially suited for use as a power transmission medium in hydraulically operated equipment.

HYDRODYNAMIC LUBRICATION. A system of lubrication in which the shape and relative motion of the sliding surfaces causes the formation of a fluid film having sufficient pressure to separate the surfaces.

HYDROMETER. An instrument for determining either the specific gravity of a liquid or the A.P.I. gravity.

HYDROSTATIC LUBRICATION. A system of lubrication in which the lubricant is supplied under sufficient external pressure to separate the opposing surfaces by a fluid film.

HYPOID GEAR LUBRICANT. A gear lubricant having extreme pressure characteristics for use with a hypoid type of gear as in the differential of an automobile. (SAE Handbook)

IMPERFECT-FILM LUBRICATION. A condition of lubrication in which the lubricant film is not continuous over the bearing area.

INHIBITOR. Any substance which slows or prevents such chemical reactions as corrosion or oxidation.

INTERFACIAL TENSION (I.F.T.). The energy per unit area present at the boundary of 2 immiscible liquids. It is usually expressed in dynes/cm. (ASTM Designation D 971-48T.)

INTERMEDIATE BASE CRUDE. See **MIXED BASE CRUDE.**

JOURNAL. That part of a shaft or axle which rotates or angularly oscillates in or against a bearing or about which a bearing rotates or angularly oscillates.

JOURNAL BEARING. A sliding type bearing having either rotating or oscillatory motion and in conjunction with which a journal operates. In a full journal bearing, the bearing surface is 360° in extent. In a partial bearing, the bearing surface is less than 360° in extent, i.e., 150°, 120°, etc.

KINEMATIC VISCOSITY. The absolute viscosity of a fluid divided by its mass density. In the English system, the standard unit of kinematic viscosity is the newt and is expressed in in^2/sec. In the c.g.s. system, the standard unit of kinematic viscosity is the stoke and is expressed in cm^2/sec. (See **VISCOSITY** and **ABSOLUTE VISCOSITY.**)

KINETIC (DYNAMIC) FRICTION. The friction between two surfaces in relative motion. Sometimes called sliding friction or the friction of motion.

LACQUER. A deposit resulting from the oxidation and polymerization of fuels and lubricants when exposed to high temperatures. Similar to but harder than varnish.

LARD OIL. An animal oil prepared from chilled lard or from the fat of swine.

LEAD NAPHTHENATE. A lead soap of naphthenic acids, the latter occurring naturally in petroleum.

LIQUID. Any substance which flows readily or changes in response to the smallest influence.

More generally, any substance in which the force required to produce a deformation depends upon the rate of deformation rather than upon the magnitude of the deformation (See, **SOLID).**

LIME BASE GREASE. A grease prepared from a lubricating oil and a lime soap.

LITHIUM BASE GREASE. A grease prepared from lubricating oil and a lithium soap.

LUBRICANT. Any substance interposed between two surfaces in relative motion for the purpose of reducing the friction and/or the wear between them.

MECHANICAL LUBRICATOR. A mechanical device for supplying lubricant to various parts of a mechanism. With this device, the lubricant is not usually recirculated.

MIXED BASE CRUDE or **INTERMEDIATE BASE CRUDE.** Crude oil, not predominantly paraffinic or naphthenic in character, found in the Mid-Continent and other districts.

MIXED BASE GREASE. A grease in which the thickening agent or base is generally a mixture of sodium or calcium soaps although other soaps may be used.

MOLD OIL. An oil used to insure easy parting of a ceramic, glass, metal or other object from the mold in which it is cast. (Also see **FORM OIL).**

NAPHTHENIC BASE. A characterization of certain petroleum products prepared from naphthenic type crudes (crudes containing a high percentage of ring type aliphatic hydrocarbon molecules).

NEATSFOOT OIL. A pale yellow animal oil made from the feet and shinbones of cattle.

NEEDLE BEARING. A rolling type bearing containing rolling elements in the form of rollers which are relatively long compared to their diameter.

NEUTRALIZATION NUMBER. A term still used in the petroleum industry, but rapidly becoming obsolete in the lubrication field. (See **ACID, STRONG ACID, STRONG BASE, TOTAL ACID,** and **TOTAL BASE NUMBERS.)**

NEUTRAL OILS. Lubricating oils of low or medium viscosity obtained in petroleum distillation and prepared without chemical treatment. They derive their name from the fact that they have not been treated with either an acid or an alkali, but have been purified by simple filtration.

NEWT. The standard unit of kinematic viscosity in the English system. Expressed in in^2/sec.

n-HEPTANE (NORMAL HEPTANE). A hydrocarbon compound (C_7H_{16}) with an octane rating defined as zero and used as a reference fuel ingredient in making motor fuel octane member tests.

NON-SOAP GREASE. A product similar to grease in appearance and consistency but containing only heavy residual stocks and mineral oil.

OCTANE NUMBER. A number indicating the knock rating or resistance to detonation of motor gasoline.

It is defined as the percentage by volume of iso-octane (C_8H_{18}) in a mixture with n-heptane. The mixture has the same knock rating under standard engine test conditions as the test fuel.

OIL. A greasy unctuous liquid of vegetable, animal, mineral or synthetic origin.

OILINESS. That property of a lubricant which produces low friction under conditions of boundary lubrication. The lower the friction the greater the oiliness.

OIL RINGS. A loose ring, the inner surface of which rides a shaft or journal causing the rings to rotate. The ring dips into a reservoir of lubricant from which it carries lubricant to the top of the shaft for distribution to a bearing.

ORGANIC ACID. An organic compound, with acid properties, obtained from organic substances such as animal, vegetable and mineral oils, for example a fatty acid.

PAD LUBRICATION. A system of lubrication in which the lubricant is delivered to a bearing surface by a pad of felt or similar material.

PARAFFIN BASE. A characterization of certain petroleum products prepared from paraffin type crudes (crudes containing a high percentage of straight chain aliphatic or paraffinic hydrocarbon molecules.)

PARTIAL BEARING. See **JOURNAL BEARING.**

PEDESTAL BEARING. A bearing which is supported on a column or pedestal rather than on the main body of a machine.

PENETRATION or **PENETRATION NUMBER.** The depth, in tenths of a millimeter, that a standard cone penetrates a semi-solid sample under specified conditions. (ASTM Designation D 217-48.) (See **WORKED PENETRATION.)**

PENETROMETER. An instrument for measuring the penetration of semi-solid substances.

PENSKY-MARTENS (CLOSED CUP) TEST. A closed cup test for determining the flash point and the fire points of oils (ASTM Designation D 93-46.) Used principally for fuel oils, asphalts, etc.

PIVOT BEARING. An axial-load, radial-load type bearing which supports the end of a shaft or pivot as on the balance wheel of a watch.

PIVOTED PAD BEARING. An axial or radial load type bearing in which the bearing surface consists of one or more pads or shoes which are pivoted in such a manner as to permit them to tip and thus promote the establishment of a hydrodynamic film.

PLAIN BEARING. Any simple sliding type bearing as distinguished from fixed pad, pivoted pad or rolling type bearings.

POISE. The standard unit of absolute viscosity in the c.g.s. system. Expressed in dyne sec/cm^2.

POLYMERIZATION. The chemical combination of similar type molecules to form larger molecules.

POROUS BEARING. A bearing made from porous material, such as compressed metal powders, the pores acting either as reservoirs for holding or passages for supplying lubricant.

POUR POINT. The lowest temperature at which a lubri-

cant will pour or flow under specified conditions. (ASTM designation D 97-47.)

PRECIPITATION NUMBER. The number of milliliters of solid matter precipitated in a mixture of oil and petroleum solvent under specified conditions. (ASTM Designation D 91-40.)

PRESSURE VISCOMETER. As applied to grease, a capillary type instrument used for determining apparent viscosity.

RADIAL-LOAD BEARING. A bearing in which the load acts in a radial direction with respect to the axis of rotation.

RATE OF SHEAR. The difference between the velocities along the parallel faces of a fluid element divided by the distance between the faces.

REYN. The standard unit of absolute viscosity in the English system. Expressed in lb sec/in^2.

RING LUBRICATION. A system of lubrication in which the lubricant is supplied to the bearing by an oil ring.

ROLLER BEARING. A rolling type bearing containing rolling elements in the form of rollers.

RUST PREVENTION TEST (TURBINE OILS). A test to measure the effectiveness of an oil in preventing the rusting of ferrous parts in the presence of water. (ASTM Designation D 665-49T.)

SAE NUMBERS—SAE OIL VISCOSITY CLASSIFICATION. Numbers applied to crankcase, transmission and rear axle lubricants to indicate their viscosity range.

SAPONIFICATION. A process in which a fat (or other compound of an acid with an alcohol) reacts with an alkali to form a soap and glycerine or other alcohol.

SAPONIFICATION NUMBER. The number of milligrams of potassium hydroxide required to saponify the fats and/or esters in a 1 gram sample of a given material. (ASTM Designation D 94-487.)

SAYBOLT UNIVERSAL VISCOSITY, (SUV OR SAYBOLT UNIVERSAL SECONDS, (SUS). The time in seconds required for 60 cubic centimeters of a fluid to flow through the orifice of the Standard Saybolt Universal Viscometer at a given temperature under specified conditions. (ASTM Designation D 88-44.)

SAYBOLT FUROL VISCOSITY. The time in seconds required for 60 cubic centimeters of a fluid to flow through the orifice of a Saybolt Furol Viscometer at a given temperature under specified conditions. (ASTM Designation D 88-44.) The orifice of the furol viscometer is larger than that of the universal viscometer, and is used for more viscous fluids.

SEMI-FLUID. Any substance having the attributes of both a liquid and a solid. Similar to a semi-solid but being more closely related to a liquid than to a solid.

SEMI-SOLID. Any substance having the attributes of both a solid and a liquid. Similar to semi-liquid but being more closely related to a solid than a liquid.

More generally, any substance in which the force required to produce a deformation depends both on the magnitude and on the rate of the deformation. (See **SOLID, LIQUID.)**

SHEAR STRESS. The force per unit area acting tangentially to the surface of an element of a fluid or of a solid.

SHOE TYPE BEARING. A pivoted pad bearing of either radial load or axial load type.

SLEEVE BEARING. A journal bearing, usually a full journal bearing.

SLIGH OXIDATION TEST. A test for determining the oxidation resistance of oils.

SLUDGE. Insoluble material formed as a result either of deterioration reactions in an oil or by contamination of an oil, or both.

SLUSHING OIL. An oil or grease like material used on metals to form a temporary protective coating against rust, corrosion, etc.

SNYDER LIFE TEST. A test for determining the sludging tendency of transformer oils. The test is now seldom used and is superseded by ASTM Designation D 670-427.

SOAP. A compound formed by the reaction of a fatty acid with an alkali.

SODA-BASE GREASE. A grease prepared from lubricating oil and a sodium soap.

SOLID. Any substance having a definite shape which it does not readily relinquish.

More generally, any substance in which the force required to produce a deformation depends upon the magnitude of the deformation rather than upon the rate of deformation. (See **LIQUID.)**

"SOLUBLE" CUTTING OIL. A mineral oil containing additives which enable it to be easily mixed with water to form a stable emulsion for use as cutting fluid.

SPECIFIC GRAVITY. The ratio of the weight in air of a given volume of a material to the weight in air of an equal volume of water at a stated temperature.

SPERM OIL. A pale-yellow oil obtained from the head cavities and blubber of the sperm whale.

SPINDLE OIL. A light-bodied oil used principally for lubricating spindles and light, high speed machinery.

SPLASH LUBRICATION. A system of lubrication in which parts of a mechanism dip into and splash the lubricant on to themselves and/or other parts of the mechanism.

SPONGE GREASE. A soda-base grease differing from the smooth, buttery soda-base greases in that it is more fibrous and sponge-like in structure.

STATIC FRICTION. The force which is just sufficient to initiate relative motion between two bodies under load.

STEAM EMULSION NUMBER (S.E. No.). The number of seconds required for an oil to separate from water when emulsified with steam and then allowed to separate under specified conditions. (ASTM Designation D 157-36.)

STEAM REFINED. With reference to lubricating oils, a term applied to unfiltered residual cylinder oils from which the lighter fractions have been distilled by the direct application of steam.

STEP BEARING. A plane surface bearing which supports the lower end of a vertical shaft.

STOKE. The standard unit of kinematic viscosity in the c.g.s. system. Expressed in cm^2/sec.

STRONG ACID NUMBER (S.A.N.). The quantity of base, expressed in milligrams of potassium hydroxide, required to neutralize the strong acid constituents present in 1 gram of sample. (ASTM Designation D 664-49.)

STRONG BASE NUMBER (S.B.N.). The quantity of acid, expressed in terms of the equivalent number of milligrams of potassium hydroxide, required to neutralize the strong base constituents present in 1 gram of sample. (ASTM Designation D 664-49.)

SULPHURIZED OIL. Oil to which sulfur or sulfur compounds have been added.

SURFACE TENSION. The contractile surface force of a liquid by which it tends to assume a spherical form and to present the least possible surface. It is expressed in dynes/cm or ergs/cm^2.

SYNTHETIC LUBRICANT. A lubricant produced by synthesis rather than by extraction or refinement.

TACKY. A descriptive term applied to greases which are particularly sticky or adhesive to metal surfaces.

TALLOW. Animal fat prepared from beef and mutton.

TAPERED PAD (LAND) BEARING. A fixed pad (land) bearing in which the surfaces of the pads are tapered so as to promote the establishment of a hydrodynamic film.

THIN FILM LUBRICATION. A condition of lubrication in which the film thickness of the lubricant is such that the friction between the surfaces is determined by the properties of the surfaces as well as the viscosity of the lubricant.

THRUST BEARING. An axial-load bearing.

TOTAL ACID NUMBER (T.A.N.). The quantity of base, expressed in milligrams of potassium hydroxide, that is required to neutralize all acidic constituents present in 1 gram of sample. (ASTM Designation D 644-49.)

TOTAL BASE NUMBER (T.B.N.). The quantity of acid, expressed in terms of the equivalent number of milligrams of potassium hydroxide that is required to neutralize all basic constituents present in 1 gram of sample. (ASTM Designation D 664-49.)

UNCTUOUS. Having a greasy, oily, or soapy feel when rubbed or touched by the fingers.

UNWORKED PENETRATION. The penetration at 77 F. of a sample of grease which has received only the minimum handling in transfer to the test apparatus and which has not been subjected to the action of a grease worker. (ASTM Designation D 217-48.)

VARNISH. When applied to lubrication, a deposit resulting from oxidation and polymerization of fuels and lubricants. Similar to but softer than lacquer.

VISCOMETER or VISCOSIMETER. An apparatus for determining the viscosity of a fluid.

VISCOSITY. That property of a fluid, semi-fluid or semi-solid substance which causes it to resist flow. It is defined as the shear stress on a fluid element divided by the rate of shear. The standard unit of viscosity in the English system is the reyn which has the units of lb sec/in^2. The standard unit of viscosity in the c.g.s. system is the poise which has the units of dyne sec/cm^2. 1 reyn = 6.895 x 10^4 poises.

VISCOSITY INDEX (V. I.). A commonly used measure of a fluid's change of viscosity with temperature. The higher the viscosity index the smaller the relative change in viscosity with temperature.

VISCOUS. Possessing viscosity. Frequently used to imply high viscosity.

WASTE. Any fibrous material such as yarn or textile waste used to supply a lubricant to a bearing through capillary action.

WASTE LUBRICATION. A system of lubrication in which the lubricant is delivered to a bearing surface by cloth waste or yarn.

WEAR. The attrition or rubbing away of the surface of a material as a result of mechanical action.

WHITE OIL. Light-colored and usually highly-refined mineral oils frequently employed in medicinal and pharmaceutical preparations, and as a base for creams, salves and ointments. Also used as lubricants.

WICK LUBRICATION. A system of lubrication in which the lubricant is delivered to a bearing surface by means of a wick.

WOOL OIL. A compounded mineral oil, used in the manufacture of woolen cloth to lubricate the wool fiber so that it will suffer a minimum reduction in staple length and will spin easily.

WORKED PENETRATION. The penetration of a sample of lubricating grease immediately after it has been brought to 77 F. and then subjected to 60 strokes in a standard grease worker. (ASTM Designation D 217-48.)

YARN. Any fibrous material, such as wool, twisted into a loose thread and added to greases for special applications. (See also **WASTE.**)

YARN GREASE. Cup, sponge, or residuum greases containing strands of wool or cotton yarn.

YIELD VALUE. When applied to a semi-solid, the minimum stress necessary to produce continuous deformation.

The ASLE Educational Committee earnestly solicits comments from all of the readers of **Lubrication Engineering** on this glossary. It is only by this method that revisions of the glossary can be made worthwhile in the sense that it covers the field of Lubrication Engineering. Comments and discussion should be sent to: H. E. Mahncke, Westinghouse Research Laboratories, East Pittsburgh, Pa.

Current Literature

(Copies of the following current literature can be obtained without charge by writing direct to the company.)

A List of 'dag' Dispersions for Industry, Acheson Colloids Co. (LE10/4), Port Huron, Mich., 4 pages.

Contains a list of 40 dispersions of colloidal graphite, molybdenum disulfide, vermiculite, and zinc oxide, giving typical applications, densities, carriers, and other important data. Recent additions to the list are dispersions which offer the advantages of the valuable new epoxy resins as bases for "dag" colloidal graphite and molybdenum disulfide dry-film coatings.

Metered Lubrication for Textile Machinery from Fibre to Fabric, Bijur Lubricating Corp. (LE-10/4), Rochelle Park, N. J., 16 pages.

Exclusively devoted to the lubrication of textile machinery, covering automatic lubrication of blending, picking, carding, combing, drawing, roving, spinning, twisting, spooling, knitting, and weaving machinery, and includes a full, illustrated page on each type of machine. Describes and illustrates how one oil pump per machine force-feeds a controlled volume of oil through a single-line distribution system to meter-units which apportion the oil in correct amounts to each bearing. The lubricator (pump and reservoir), distribution system and meter-units are fully explained and major advantages of the Bijur system are discussed.

Anti-Corrosion Lubricants, Bulletin BK-20, Keystone Lubricating Co. (LE10/4), 21st Clearfield & Lippincott Sts., Philadelphia 32, Pa., 8 pages.

Covers the particular group of Keystone specialized lubricants ideally used when vacuum pump cylinders, pump packing glands, plugtype valves and other mechanical equipment, plus process piping, are used in corrosive service. Designed to offer a detailed list of correct lubricants for many specific applications within a wide range of industries under all types

(Continued on Page 220)

THE BOUNDARY FRICTION OF VERY WELL LUBRICATED SURFACES

by E. Rabinowicz*

Experimental evidence is presented showing that the major contribution to frictional forces under certain cases of boundary lubrication may arise from shearing forces within a lubricant film itself. In the absence of plowing, good lubricants such as copper palmitate reduce the contribution of metallic contacts to a minor part of the overall friction. It has also been demonstrated that when the softer member of a rubbing pair of metals is held fixed, the friction is independent of the choice of the harder metal.

The modern theory of friction, the welding theory, gives rise to a simple formulation for the friction coefficient of sliding surfaces (Bowden & Tabor[1]). The real area of contact A under a load L is given by the expression

$$L = pA \tag{1}$$

where p is the mean flow pressure of the softer metal.

For smooth unlubricated surfaces, the friction force F_m required to shear this area, assuming the formation of welds of shear strength s_m, is given by

$$F_m = s_m A \tag{2}$$

whence we have for the friction coefficient f_m

$$f_m = F_m/L = s_m/p \tag{3}$$

Bowden, Gregory and Tabor[2] modified these equations to cover the case of lubricated sliding. In boundary lubrication it is well known that a lubricant diminishes, but does not entirely eliminate, the extent of metallic contact. Hence it was assumed that over a fraction α of the surface metallic contact was still maintained, while over the remaining fraction $[1 - \alpha]$ of the surface the lubricant separated the surfaces. Hence Equation 2 becomes

$$F = A \{\alpha s_m + [1 - \alpha]\ s_1(p)\} \tag{4}$$

The shear strength s_1 of the lubricant has been written in the form $s_1(p)$, in which s_1 is indicated to be a function of p, because it is very markedly dependent on the pressure.

Dividing Equation 4 by Equation 1 we obtain

$$f = \alpha f_m + [1 - \alpha]\ s_1\ (p)/p \tag{5}$$

For most soft substances used as lubricants the shear strength is, to a first approximation, proportional to the normal pressure[3] and we may call this constant f_1. Thus we may write

$$f = \alpha f_m + [1 - \alpha]\ f_1 \tag{6}$$

It will be seen that f_1 is the friction coefficient that would prevail in the absence of any metallic contact.

Bowden, Gregory and Tabor[2] assumed that the first, or 'metallic,' term in Equations 4 to 6 was the larger and more important one. Later work by Rabinowicz and Tabor[4] has suggested, however, that while this might be true in the case of poorly lubricated surfaces, for well-lubricated surfaces the second, or 'lubricated' term was far larger. Using a crude analysis based on wear studies with radioactive metals they obtained the metallic component as only 2.5 per cent of the total friction force for copper surfaces lubricated by copper palmitate. To allow for the indirect nature of the calculation and the varying properties of copper palmitate on different metals, it may be assumed that, using this lubricant over a wide range of metals, 20 per cent or less of the total frictional force is attributable to metallic contact of the sliding surfaces.

It follows that for smooth surfaces in which roughness effects are small, and under conditions where plowing does not occur, most of the friction force is caused by shear within the lubricant film, and will be independent of the nature of the sliding metals as long as other variables are kept constant. Hence the value of the friction coefficient should remain nearly constant as the nature of the contacting metals is changed. A series of experiments has been carried out to test this prediction.

Experimental. Sliding tests were carried out in the apparatus shown in Fig. 1, which consists of a hemispherically ended, 1/8″ diameter rider held stationary with respect to a horizontal flat specimen mounted on a rotating steel disk. The rider is loaded by a dead weight, and as a result of the friction force is deflected against the strain gauge ring. Both the change in resistance of the strain gauge due to the friction force, and the change in resistance of an interruptor mechanism on the rotating disk, are displayed on a Sanborn 2-channel recorder. A precision of about 1 per cent could be obtained with this apparatus for most of the measurements.

The surfaces were prepared by lapping on fine emery paper in air, applying the lubricant, copper palmitate, in powder form, and heating the surface until the copper palmitate melted and could be spread over the surface.

When the surfaces had cooled, sliding experiments were carried out at a load of 1000 g and velocities ranging from 3.10^{-4} to 30 cm/sec.

Results. Fig. 2 shows an original friction trace for steel sliding on steel. The friction coefficient is plotted as a function of time, and some 50 revolutions are shown. It will be seen that during the first revolution the friction coefficient was abnormally high, and this is undoubtedly caused by the need to plow through the thick lubricant layer. At about the third revolution the friction is at a minimum, and thereafter the friction gradually increases as

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lubricant is wiped off the surface.

A point of some importance is that the friction varies during one revolution, and that this variation is almost exactly reproduced during subsequent revolutions. While this variation may be partly instrumental in character — the sliding surface being not perfectly normal to the axis of rotation of the steel block — and partly due to a roughness effect producing differences in friction as the rider travels first along and then across the lapping marks, most of the fluctuation is due to differences in the value of α caused by different degrees of penetration of the lubricant layer at different points along the sliding track. Since we are interested mainly in low values of α and hence of f, the minimum rather than the average value of f was measured.

Fig. 3 shows a series of measurements sliding various metals on steel. Runs were carried out at different sliding speeds, and the minimum coefficient of friction was measured in each case. It will be seen that the points all lie on approximately the same line.

Figs. 4 & 5 show analogous results obtained with lead and with zinc. Similar results have also been obtained using a liquid lubricant, namely a solution of palmitic acid in cetane.

It should be carefully noted that in sliding e.g. lead on steel or steel on lead, the frictional results are characteristic of lead, not of steel, since the softer metal determines the flow pressure. A metal other than lead but of the same hardness would give similar results.

The constant friction values obtained with the lubricated metals are not observed with the corresponding unlubricated metals. Thus while the friction coefficient of lubricated titanium on steel is nearly the same as that of steel on steel (Fig. 3), the unlubricated values differ by more than a factor of 2 (titanium on steel, f = 0.23; steel on steel, f = 0.53).

Discussion. We are now in a position to consider what are the factors affecting the friction coefficients obtained in the presence of good boundary lubricants. The problem is analogous, in many ways, to that of full-fluid lubrication by a non-Newtonian liquid with a number of important differences. Whereas in full-fluid lubrication the friction coefficient is quite independent of the nature of the bounding surfaces, here it is only nearly independent. A second difference is that one important variable, namely film thickness, is not easily controllable in the case of boundary lubricated films. For, as has been suggested by the work of Bowden and Tabor,[1] in the case of boundary lubricated sur-

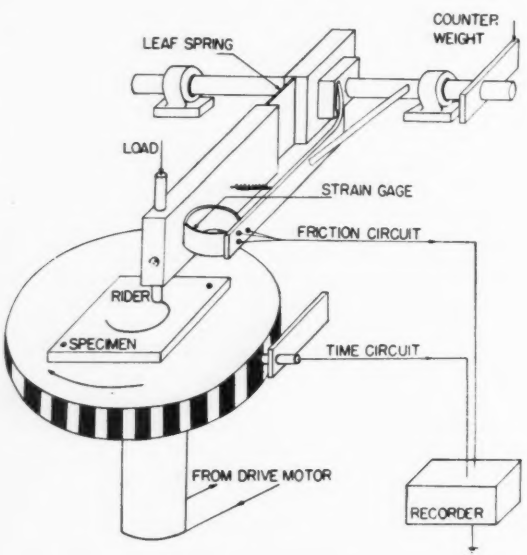

Fig. 1 Sketch of friction apparatus.

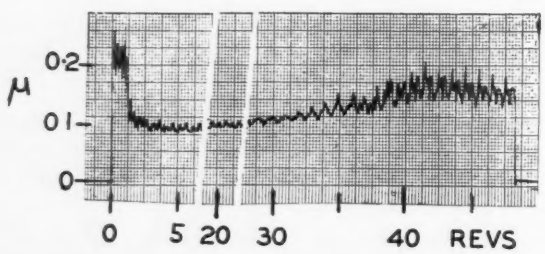

Fig. 2 Friction trace (covering 50 revolutions) of steel sliding on steel, lubricated by copper palmitate. Load 1000 g, Velocity 1 cm/sec.

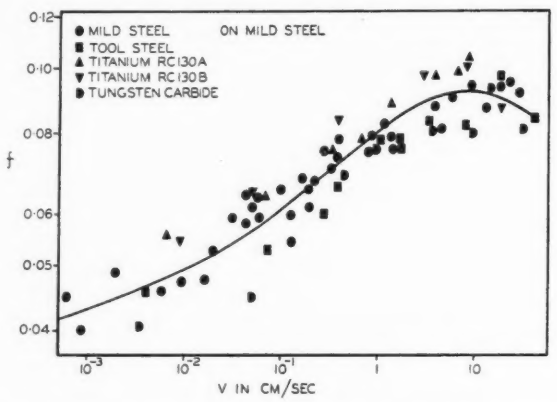

Fig. 3 Friction-velocity plot for various riders (all as hard as mild steel or harder) sliding on mild steel. Load 1000 g, Lubricant copper palmitate.

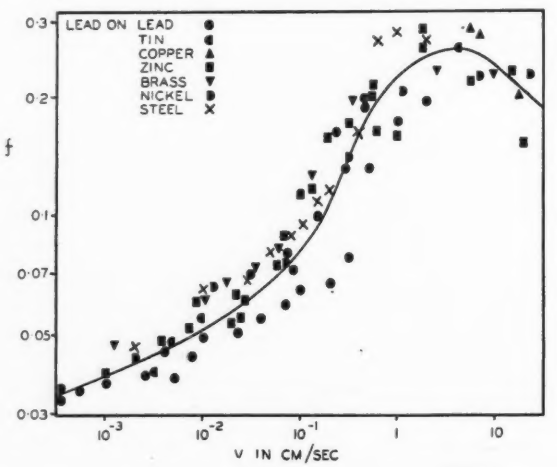

Fig. 4 Friction-velocity plot for a lead rider on various metal flats (all as hard as lead or harder). Load 1000 g, Lubricant copper palmitate.

faces only a very few monolayers of the lubricant, characteristic of the sliding combination, are interposed between the sliding surfaces, and no simple way of systematically varying this number is available, since the rider probably wipes off all but a few layers after the first one or two revolutions.

Other variables, however, that are of importance in full-fluid lubrication, namely shear rate, pressure and temperature, have their analogues in our experiments. The shear rate in our experiments is defined by the velocity, since the thickness of the lubricant layer is assumed more or less constant. The variation of friction coefficient with pressure, for a number of metals, is shown in Fig. 6, which shows the data obtained with lead, indium, zinc and steel, and indicates their Vickers hardness in kg/mm^2.

The actual friction-velocity curves for all have the same general shape; namely, a positive slope up to about 3 cm/sec and then a falling characteristic. These features are in good agreement with those of other investigators. Thus the positive characteristic agrees with the observations of Barwell and Milne[5] working with stearates on steel, while the maximum and descending portions of the curve have been shown by Murray and Burwell[6] to cover the sliding of a number of long chain compounds on steel and aluminum.

A curve of the same general shape was found by Roth, Driscoll and Holt[7] to apply also to the sliding of rubber and by Burwell and Rabinowicz[8] to the sliding of unlubricated indium and lead. It seems therefore to be a widespread phenomenon. Thermal activation may explain the initial positive slope of the f-v curve, whereby a low friction force assisted by thermal fluctuations in the positions of the molecules can produce movement at very low velocities, while to produce larger sliding velocities larger friction forces are required. As the velocity is increased shear begins to take place at the film-metal interface rather than within the film, since there is not sufficient time for the formation of a strong surface bond. At the same time brittle fracture, and thermal softening caused by frictional heat, may be initiated, and in consequence the friction coefficient reaches a maximum value and thereafter declines.

The results of Fig. 6 show that, with the exception of the somewhat anomalous behaviour of lead, at the higher velocities the friction increases with decreasing pressure, but at lower velocities this tendency seems to become reversed and friction and pressure vary directly. Boyd and Robertson[3] have obtained this latter effect with their fatty acid derivatives, and White[9] working with various soaps, has also found that the friction coefficient increases as the pressure is increased. His friction coefficients are much lower than those observed in our tests since his shear rates were correspondingly lower.

The considerable scatter in our experimental results arises from a number of causes. First there are instrumental uncertainties of 1 to 2%. Then there are roughness effects of perhaps 5% (Strang & Lewis[10]), which arise because we are measuring minimum and not average friction values. Next there are variations in α, which we have postulated as small. After all these have been allowed for, some error still remains, and probably arises from two causes. Firstly, the plastic properties of the copper palmitate may be somewhat influenced by the heat treatment given, and no attempt was made to standardize this. Secondly, crystal orientation of the copper palmitate may influence the shear process (e.g. allowing shear in a number of parallel planes with a consequent reduction in shear stress). In general, metal on like metal seems to give somewhat lower friction values than metal on unlike metal, and it may be that the more uniform stress distribution in the former case allows shear in more than one plane.

To summarize, we may say that the experiments show that with copper palmitate as a lubricant the coefficient of friction is defined by the nature of the softer metal present in the sliding combination and the velocity, and this suggests that for well-lubricated surfaces the nature of the surfaces, while of great importance in determining the wear, is of little significance in affecting the coefficient of friction, and that the frictional properties are very largely defined by the physical variables acting on the lubricant.

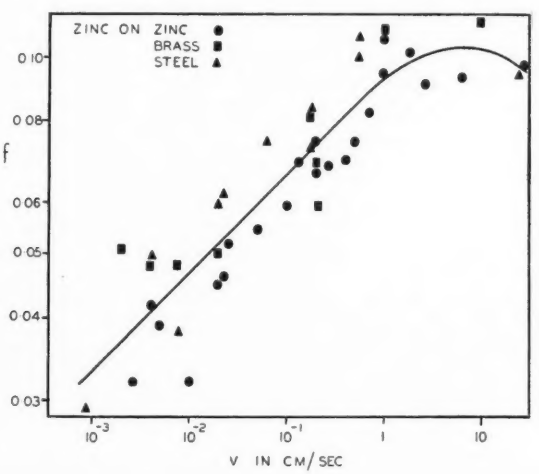

Fig. 5 Friction-velocity plot for a zinc rider on various metal flats (all as hard as zinc or harder). Load 1000 g, Lubricant copper palmitate.

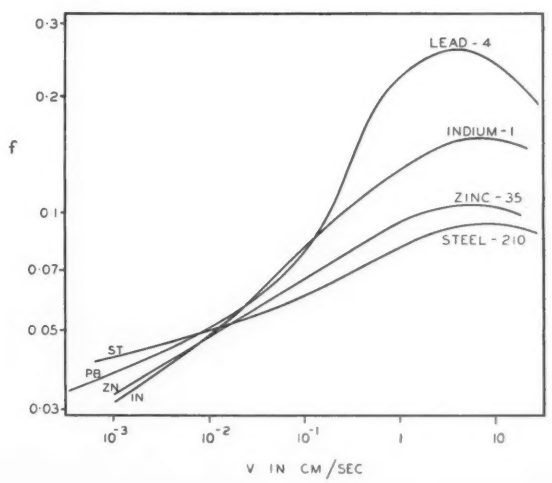

Fig. 6 Summary of friction-velocity curves of metals studied.

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[8]Burwell & Rabinowicz: The Nature of the Coefficient of Friction. J. Appl. Phys. 24, 1953, pp. 136-139.
[9]J. R. White: Frictional Properties of Soaps at High Pressures. Paper presented at ASLE 9th Annual Meeting, Cincinnati, April 5, 1954.
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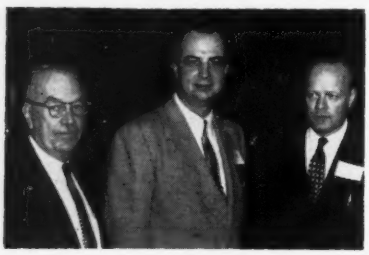
(See Commentary & Author's closure, p. 230)

Section News

Notice to Section Secretaries: To insure early and adequate coverage of your Section's activities, all Section News copy (including Summaries of papers presented, Election of Officers, Photographs, etc.) must be received by the ASLE National Office 1½ months prior to the month of LE publication.



INDIANAPOLIS, March meeting. Tour of the Lebanon Plant of the Honan-Crane Corp., at the invitation of R. L. Strawbridge, Manager, and suggestion of J. R. McCoy, Technical Service Director, including the quality control and testing laboratory where filtering problems are attacked and manufacturing recommendations made. Pictured above from left to right are: E. D. Harkins, Sr. (Section Chairman), The Farval Corp., Mr. Strawbridge, and Mr. McCoy. (Submitted by R. C. Fatout, Sec'y-Treas.)

BOSTON, April meeting. (Held in Portland, Maine, and arranged by A. H. Smith, Hollingsworth & Whitney Co., and L. M. Chaput, Esso Standard Oil Co.) C. L. Pope (ASLE Past President), Eastman Kodak Co., presented a paper entitled "Paper Mill Lubrication," supplemented by slides and followed by a Question & Answer period. (Submitted by A. S. McNeilly, Secretary.)

CHICAGO, May meeting. Election of Officers (see ASLE Directory), together with an address by H. A. Erickson, D. A. Stuart Oil Co., entitled "Machining Stainless Steel & Titanium," followed by a film furnished by the Jones & Lamson Machine Co., entitled "Research in Metal Turning."

June meeting. Annual golf party held at the Cog Hill Country Club, with Dr. A. B. Wilder, E. I. duPont deNemours & Co., winning the Alfred A. Paul trophy awarded by the Brooks Oil Co. for low score under the Peoria Handicap System. (Submitted by W. P. Green, Vice-Chrmn.)

CINCINNATI, May meeting. Election of Officers (see ASLE Directory. Submitted by R. L. Peters, Vice-Chrmn.)

DETROIT, May meeting. Election of Officers (see ASLE Directory. Submitted by G. W. Mason, Secretary.)

LOS ANGELES, February meeting. Dr. H. E. Mahncke, Westinghouse Research Laboratories, presented a paper entitled "Lubrication Problems Encountered by a Consumer," in which he pointed out that most lubricant producers furnish excellent information on their products and it is up to a designer to correctly interpret this information for the application at hand. His own experience has indicated that the majority of problems involving lubrication turn out to be actually mechanical design problems rather than inadequacy of the lubricant, and he suggests that the universal use of absolute viscosity values in centipoises rather than the various kinematic viscosities generally employed would eliminate many of these design faults.

March meeting. 'Steel Mill Lubrication Problems," prepared by E. E. Perso, A. C. Keiser, Jr., W. H. Mandy, and M. S. Clark, all of The Texas Co., was presented by Mr. Perso in which he pointed out that water and mill scale contamination, together with heat, are the principal deteriorating factors affecting lubricants used in the steel industry. Preventing contamination by installing better shields and seals is the most practical approach to the problem of greater steel mill lubricant life; however settling, heating, centrifuging, and filtering can all be used to advantage. These techniques help prevent or eliminate the viscous water and oil emulsions often found in steel mill oil sumps. Reduced wear, greater equipment life, greater production and safer working conditions have resulted from the installation of automatic lubricating mechanisms on most steel mill equipment. (Submitted by R. S. McCord, Sec'y-Treas.)

NEW YORK, May meeting. Election of Officers (see ASLE Directory), together with an address by T. Badger, Westinghouse Electric Co., entitled "Plant Lubrication." (Submitted by E. Landau, Director.)

NORTHERN CALIFORNIA, May meeting. Election of Officers (see ASLE Directory), together with an address by C. A. Winslow, President, Winslow Engineering Co., entitled "Oil Filtration in Modern Industry." Mr. Winslow discussed the historical development of filters as applied to modern machinery, as well as the advantages and disadvantages of full-flow and pressure by-pass types, filters with chemical and mechanical absorption units, the supplemental use of oil coolers, and recent developments such as micronic filters.

June meeting. Annual dinner dance held at the Alameda Naval Air Station Commissioned Officers Club. (Submitted by R. H.

Decker, retiring Sec'y-Treas., & A. C. West, Sec'y-elect.)

ST. LOUIS, May meeting. Election of Officers (see ASLE Directory. Submitted by L. L. Armantrout, retiring Chrmn.)

TWIN CITIES, May meeting. Election of Officers (see ASLE Directory), together with an address by R. Q. Sharpe, Socony-Vacuum Oil Co., entitled "Hydraulic Systems, Care & Operation." (Submitted by C. D. Johnson, Secretary.)

WHEELING, May meeting. Election of Officers (see ASLE Directory. Submitted by J. A. Martin, Sec'y-Treas.)

Personals

A. F. Brewer, Consulting Editor of **Lubrication Engineering** and this year's recipient of the ASLE Life Membership Award, has announced his retirement from The Texas Co., New York, N. Y., after 35 years of service (32 of these years as Editor of The Texas Company's monthly publication, "Lubrication.") Mr. Brewer expects to continue literary activities and to devote more time to his hobbies at his new home on the Indian River in Florida.

At the first annual meeting of the National Fluid Power Association held recently in Edgewater Park, Miss., **B. N. Ashton,** Electrol Inc., was elected President, with **L. S. Barksdale,** Barksdale Valves Co., **L. H. Schuette,** Sundstrand Machine Tool Co., and **B. R. Teree,** The Weatherhead Co., elected as Directors.

R. W. Flynn, Supervisor of Product Application, Gulf Oil Corp., New York, N. Y., has been presented the 20-year symbolic Gulf pin award.

The Board of Directors of Commercial Filters Corp., Melrose, Mass., annouces the election of **R. L. Fielding** as President & Treasurer.

T. M. Murphy has been appointed Manager of Industrial Sales, Alemite Div., Stewart-Warner Corp., Chicago, Ill., succeeding **E. R. Harris** who has become Distributor of Alemite lubrication products and Stewart-Warner instruments at St. Louis, Mo.

G. B. Coale has been appointed General Manager of Baroid Sales Div., National Lead Co., Houston, Tex., succeeding **G. L. Ratcliffe** who will remain active as Vice-President.

For information concerning the **27th International Congress of Industrial Chemistry** to be held in Brussels, Belgium, September 11-19, write: Consulat General de Belgique, 333 N. Michigan Ave., Chicago 1, Ill.

J. P. Hamer, Standard Oil Development Co., Linden, N. J., co-authored and presented before the SAE meeting in Atlantic City a paper entitled "Vapor Locking Characteristics of Passenger Cars."

Obituaries: **A. W. Ward,** Chairman of the Board of The Brooks Oil Co., Pittsburgh, Pa., May 28; **F. Buckner,** Alemite Co., Buffington, Ind., Spring '54.

Book Reviews

VISCOSITY OF LUBRICANTS UNDER PRESSURE, by M. D. Hersey & R. F. Hopkins; American Society of Mechanical Engineers, New York, 1954, 87 pages, price $5.00.

The viscosity of luricants under pressure is an important subject and has naturally received attention of many investigators over the years. Unfortunately the information so obtained has been scattered in many journals and countries and has not been in a form for coordinated study. Not only have the articles appeared in different languages but the measurements were made at different pressures and temperatures and the results were expressed in different units. In behalf of the Special Research Committee on Lubrication of ASME, Mayo D. Hersey and Richard F. Hopkins reviewed published viscosity-pressure data on lubricants prior to 1952 and have now presented the coordinated results in an ASME publication under the above title.

This new publication reviews and coordinates twelve experimental investigations made in England, Germany, Japan, Russia and the United States over a period of thirty-five years. The tests were made on 148 lubricants comprised of 25 fatty oils, 94 petroleum oils, 17 compounded oils and 12 other lubricants. Data are coordinated by means of sixty tables in which the results originally appearing in diversified units are compared. The methods proposed for correlating viscosity-pressure characteristics of oils with properties determined at atmospheric pressures are reviewed and illustrated. Pertinent aspects such as experimental work on heavily loaded bearings, lubrication calculations, and additional techniques for viscosity are covered. Conclusions and recommendations are presented. Other chapters give the required computation of the temperature coefficients of viscosity, method of computing pressure coefficients, a bibliography of 189 items, and symbols used.

S. K. T.

New Products

MAGNETIC SEPARATOR. The new Houdaille magnetic separator, a small compact unit (10 gpm soluble oil model: 20" x 7-⅞" x 6-½"), has been designed to provide a constant supply of clean coolant for all types of machine tools. Contaminants are removed by means of permanent ring magnets completely enclosed in a revolving cylinder driven by a 1/70 hp (4.8 rpm) gear head motor. Turbulent flow of coolant keeps metallic particles in suspension until attracted by magnetic field; adjustable, non-magnetic wiper trough collects particles carried out of solution by magnetic discs. Available in 10 and 20 gpm capacities for soluble oils, 5 and 10 gpm for mineral oils, flexible design makes installation easy on all types of machine tools. Unit features five 2" ports, drilled and taped (three of these may serve as inlet, two as outlet); three removable plugs are supplied for insertion in unused ports. For complete details, write: Honan-Crane Corp. (LE10/4), 818 Wabash Ave., Lebanon, Ind.

HEAVY SIGHT FEED VALVES. A new heavy sight feed valve has been developed to control dispensing of liquid volume and to permit visual observation of flow. Designed primarily for pressure or gravity oiling systems on paper mills, steam and gas engines,

(Continued on page 217)

THE REACTION OF ADSORBED STEARIC ACID WITH COPPER AND COPPER OXIDE

by A. Dobry*

When a film of stearic acid is adsorbed on a copper surface, initially only about 26% of the acid reacts with the surface oxide. In a hydrogen atmosphere, no reaction at all takes place with oxide-free copper. Thermodynamic calculations indicate that stearic acid should react with cuprous and cupric oxide and also with copper under oxidizing conditions, but that, under inert or reducing conditions, copper will not react. The effect of this lack of reactivity in diminishing boundary lubricating effectiveness is discussed.

As is well known, films of adsorbed polar materials greatly reduce friction in non-hydrodynamic lubrication. The nature of the lubrication is affected by the composition of the polar substances and the solid surfaces onto which they are adsorbed, as well as by interactions between adsorbent and solid; e.g., fatty acids are good examples of such polar additives. These acid boundary additives retain their lubricating powers to much higher temperatures when used with reactive metals such as copper or zinc than with unreactive surfaces such as platinum or glass.[1] In general, lubrication is effective up to the melting point of the acid itself when used on inert surfaces but, with less passive metals, lubricity is further extended up to the melting point of the corresponding soap (for instance, copper stearate in the case of copper and stearic acid). A number of workers have demonstrated that fatty acids adsorbed on surfaces of active metals react with the substrate to give metal soaps.[1,2] Presumably, the adsorbed film serves to separate and lubricate the rubbing surfaces only so long as it remains rigid, and when the temperature rises above its melting point, the film softens and the rubbing surfaces come together with a resultant increase in friction.

Such an increase in friction may occur in two possible ways. The temperature of the whole bearing may rise above the melting point of the adsorbed soap, disrupting the entire boundary film. An alternative possibility is suggested by the well known fact that, under conditions of boundary lubrication, local hot spots continually occur, wherein microscopic areas may momentarily reach temperatures of several hundred degrees centigrade. It is generally believed that these hot spots are caused by asperities breaking through the adsorbed film and forming metal to metal welds which are immediately broken with the evolution of heat. Such hot spots will, therefore, disrupt the boundary lubricating layer in the area immediately around the hot spots and give rise to more extensive welding, the evolution of more heat, and an increase in friction. Since the temperature of these hot spots increases with increasing load and running speed, a heavily loaded high speed bearing might actually seize due to this self-propagating reaction even though the bearing, as a whole, is quite cool. Therefore, it seems quite worthwhile to study more closely the formation and nature of these adsorbed soap films.

*Westinghouse Research Laboratories, East Pittsburgh, Pa.

This paper was sponsored by the ASLE Technical Committee on Lubrication Fundamentals, and presented at the ASLE 9th Annual Meeting, Cincinnati, April 6, 1954.

A fundamental question is to what extent the adsorbed organic acid reacts with the metal substrate. A convenient system for study is stearic acid and copper, a common bearing alloy constituent. Both of these substances are easily obtained in pure form.

Previous workers have obtained data which indicate that only a portion of an adsorbed monolayer of stearic acid will react immediately with a copper substrate. Of course, the reaction is actually with cuprous oxide since, in air, all clean copper surfaces rapidly oxidize to Cu_2O at room temperature.[3] Bowden and Moore[1], who studied this reaction by putting stearic acid monolayers on radioactive copper and measuring the activity which could be removed by Soxhlet extraction with benzene, concluded that when stearic acid was adsorbed from benzene solution, less than one monolayer of the stearic acid reacted initially with the metal. They found that when they placed a Langmuir-Blodgett monolayer of stearic acid on a copper surface and allowed it to stand for 18 hours or heated it to 110 C. for 15 minutes, only about 0.14 atom of copper reacts for every molecule of acid in the monolayer. They interpreted this as signifying that their procedure lost 75% of the cupric stearate activity, due to adsorption on their equipment, since reaction was presumed to be complete. Consequently, they adopted an empirical correction factor of four.

Since the present work was begun, this conclusion was apparently refuted by Beischer's work[2] in which he found that if radioactive stearic acid is placed in a clean copper surface and the surface is heated until reaction occurs, initially only about 30% of the stearic acid reacts. Here, there can be no possibility of the results being in error due to adsorption on apparatus since, in this technique, unreacted stearic acid is removed and the remaining stearic acid is measured. Therefore, Bowden and Moore are apparently mistaken in assuming that a Langmuir-Blodgett monolayer reacts completely. The molar ratio of copper to stearic acid (0.14 to 0.30) seems to indicate quite clearly that, in the initial reaction of the Langmuir-Blodgett monolayer, about 30% of the stearic acid reacts to give cupric stearate.

Bowden and Moore's data on the reaction of

copper with a benzene solution of stearic acid were difficult to interpret quantitatively in this fashion. Therefore, experiments were carried out to measure the exact extent of the initial reaction of adsorbed monolayers. Four 30 cm. strips of 2.54 cm. wide, 0.013 cm. electrolytic copper foil were cut and coiled into spirals. The coils were cleaned in an etching solution (1000 ml. H_2SO_4, 1000 ml. H_2O, 245 ml. HNO_3, 8 ml. HCl), washed repeatedly with distilled water and then with methanol and dried in a stream of dry air. Each coil was weighed on a microbalance, immersed in a 0.1% solution of reagent grade stearic acid in reagent grade benzene for 2 minutes and washed twice with reagent grade benzene. The coil was placed on adsorbent tissues for half an hour to allow it to dry and then reweighed. The difference between the initial and final weights of the coil represented the weight of stearic acid adsorbed.

Bigelow, Pickett and Zisman[4] have shown that monolayers of stearic acid can be laid down on solid surfaces merely by dipping the clean solids into solutions of stearic acid. These films are both hydrophobic and oleophobic, that is, they are not wetted either by water or by organic liquids. In fact, this property furnishes a sensitive test for the presence of such monolayers. Drops of water and benzene were placed on some of the copper coils prepared in the manner described above and it was found that they did not wet the surface. This seems to indicate that the stearic acid adsorbed on the coils was actually present in the form of a close-packed monolayer. Furthermore, one can easily calculate the amount of stearic acid that would be adsorbed on the coil as a monolayer if the actual surface area of the coil is assumed to be equal to its geometrical area. The cross sectional area of a stearic acid molecule in a Langmuir-Boldgett monolayer is 21.0 $Å^2$.[5] The geometrical area of the strip is 2 x 2.54 x 30 = 152.4 cm^2. A monolayer of stearic acid of this area would weigh

$$\frac{152.4 \times 284.47}{21.0 \times 10^{-16} \times 6.023 \times 10^{23}} = 3.44 \times 10^{-5}\ g = 34.4\ \mu g$$

The amounts of stearic adsorbed on the coils ranged from 30 to 154μg which is just what would be expected if a monolayer were formed, since the actual surface areas will range up to several times the geometrical area.

When the coils are pulled out of the stearic acid solution, some solution is dragged out on them. Evaporation leaves a visible deposit on the coils and the weight of stearic acid is much too great. The two washings serve to remove this excess acid. Preliminary tests showed that constant weight is attained after two washings.

After the stearic acid coated coils were weighed, they were extracted overnight with 150 ml. of reagent grade benzene in Soxhlet extractors. After extraction, the coils were dried and re-weighed. Since the final weights were equal to the initial weights minus the amount of cuprous oxide removed (within experimental error), the extraction must have removed virtually all of the stearic acid and soap. The benzene solutions were evaporated down to about 50 ml. and they, as well as the stearic acid solutions, were then extracted with three 5 ml. portions of 10% H_2SO_4. The combined acid extracts from each coil were then analyzed for copper by neutralizing to pH 9 with concentrated ammonium hydroxide, adding 5 ml. of 10% aqueous ammonium citrate, diluting to 25 ml. and extracting for exactly two minutes with 5 ml. of reagent grade CCl_4.[6] After filtering the CCl_4 solution through a plug of glass wool to remove suspended water, its optical density was measured at 440 mμ in a Beckman Model DU Spectrophotometer. A standard curve was prepared by running this analysis on measured amounts of a standard aqueous solution of copper sulfate. A blank value of 1.56 μg copper was obtained as will be described in a later section. All solutions were made up with distilled water which had been redistilled from a pyrex still since it was found that the ordinary distilled water contained appreciable amounts of copper.

Analysis of the stearic acid solutions in which the copper coils had been dipped, showed that only a little copper went into solution in them. Every 2 atoms of copper that went into solution represented a molecule of Cu_2O removed from a coil and to the measured weight of stearic acid adsorbed by the coil must be added $(16 + 2 \times 63.57)/63.57$ times the mass of copper removed in order to correct for this.

On later runs, the extracted coils were used without further cleaning. Thus, the first four results in Table I were obtained on etched coils; the next four results on coils that had been treated once with stearic acid; and the last four, on coils that had been treated twice with stearic acid. The stearic acid treatment seems to reduce the surface area available for adsorption.

If the corrected weight of stearic acid is plotted against the corrected copper analysis (Fig. 1), a fair correlation is found between copper extracted and the amount of stearic acid adsorbed. To find

Cu Found in Extract of Coils (μg)	Cu Found Minus Blank (μg)	Wt. Stearic Acid (μg)	Wt. Cu_2O Lost in Dipping (μg)	Corrected Wt. Stearic Acid (μg)
11.0	9.44	154	1	155
10.8	9.24	148	1	149
8.7	7.14	125	1	126
5.9	4.34	116	1	117
4.5	2.94	57	1	58
3.0	1.44	80	1	81
4.6	3.04	74	1	75
7.5	5.94	118	1	119
4.3	2.74	41	3	44
7.4	5.84	45	3	48
7.3	5.74	30	13	43
5.5	3.74	52	4	56

Table I Stearic acid adsorbed on and copper removed from copper coils.

Runs with Copper		Runs without Copper	
Run	Micrograms Copper	Run	Micrograms Copper
8	2.0	17	2.2
9	1.3	18	1.9
10	2.1	19	1.1
11	1.1	20	1.7
12	1.7	21	2.5
13	1.3		
14	0.7		
15	1.5		
16	0.9		

Table II Copper found in benzene extracts from reduced copper.

the best value of the ratio of these quantities, the least squares line was found. Since neither the amount of stearic acid nor the amount of copper has a negligible variance relative to the other, it is necessary to find the standard deviations of both types of measurements.

A value for the standard deviation of the copper analyses was obtained from the determination of the blank. This amounted to 0.49 micrograms of copper.

In a separate set of experiments, the copper coils were weighed, washed in benzene, dried, reweighed, washed in benzene, and so forth. The standard deviation of a single weighing was found to be 17 micrograms. Since the amount of stearic acid is determined by taking the difference between two such weighings, its standard deviation $S = \sqrt{2} \times 17 = 24$ micrograms of stearic acid. (The standard deviation of the amount of Cu_2O dissolved by the stearic acid solution is negligible compared to this.)

It is obvious that the largest source of error lies in the weighings. Tests showed that this variability is associated with the large surface area of the object weighed and is presumably due to adsorption of moisture in a balance room with an uncontrolled atmosphere. Although the variance of the copper determination is smaller, its relative value is still quite appreciable. The inaccuracies in this determination are probably due to contamination of the extremely dilute copper solutions in the course of analysis.

Calculation of the line which passes through the origin and minimizes the sum of the perpendicular distances from the line to the observed points[7] gives a slope of 0.0586μg Cu/μg stearic acid. This corresponds to a molar ratio of 0.26.

The variance of this quantity is somewhat difficult to compute directly but we can easily determine the variance of the mean of the ratios obtained from each individual experiment. This mean should certainly be a poorer estimation of the true ratio than is the slope of the least squares line and, therefore, its variance should be greater than that of the least squares line slope. If we compute the standard deviation in this way, we find it to be 0.148 and, since there are 12 experiments, standard deviation of the simple mean is then $\frac{0.148}{\sqrt{11}} = 0.04$. The ratio of the moles of copper removed by extraction to the moles of stearic acid adsorbed is apparently, therefore, 0.26 ± 0.04.

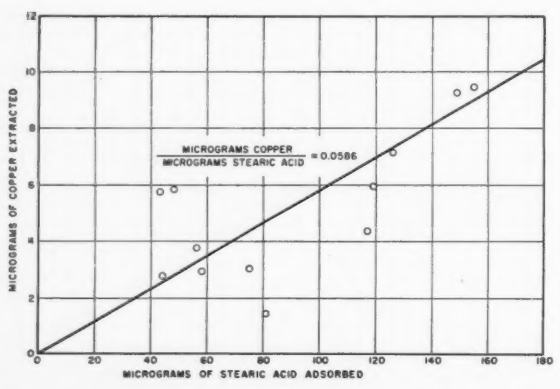


Fig. 1. Adsorption of stearic acid on copper foils vs. extractable copper formed.

It is interesting to compute the expected value of the standard deviation of the mean of the individual ratios from the known variances for the amounts of stearic acid and copper. This quantity is 0.074, or just half of the value which was actually found. The difference may be due to variations in the exact extent of reaction of adsorbed stearic acid with its cuprous oxide substrate.

If one assumes that the reaction which took place resulted in the formation of cupric stearate, then 52% of the adsorbed stearic acid should have reacted. Since Beischer found that only 30% of adsorbed stearic acid reacted under more strongly oxidizing conditions, this hypothesis is untenable and the initial reaction of stearic acid adsorbed from solution onto a cuprous oxide surface must be the conversion of 26% of the stearic acid to cuprous stearate.

The cubic cuprite (Cu_2O) lattice consists of a body centered cubic oxygen lattice with $a_o = 4.252$ Å, superimposed on a face-centered cubic copper lattice so that each oxygen atom is surrounded by a tetrahedron of copper atoms.[8] (See Fig. 2.) According to Preston and Bircumshaw[9], when copper is oxidized in air at room temperature, the preferred orientation is for the (111) plane of the copper oxide to be parallel to the metal surface. In (111) planes containing copper, there is one copper atom for every

$$(\sqrt{3}/4)a_o^2 = (\sqrt{3}/4)\ (4.252)^2 = 7.8\ \text{Å}^2$$

Since the cross-sectional area of stearic acid in a monolayer is 21.0 Å^2 each stearic acid molecule adsorbed on the Cu_2O surface should have about 2.6 copper atoms available to it for chemical reaction. Even if one takes planes at somewhat different angles, the amount of copper per unit area will be at least enough to furnish a copper atom for each stearic acid molecule. It is, therefore, difficult to understand why only about one quarter of the adsorbed stearic acid reacts.

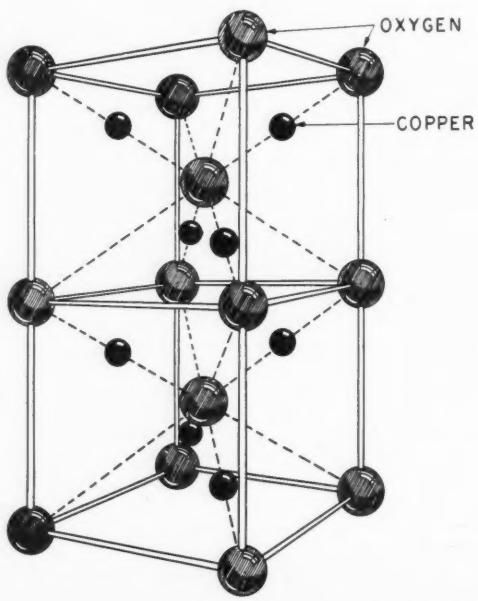


Fig. 2. Cuprous oxide.

Of course, only a portion of the cuprous oxide surface will consist of copper containing (111) planes. Other sections might expose planes which consist entirely of close-packed oxygen atoms. Since these oxygen atoms will not enter into the reaction of stearic acid with the oxide to give cuprous stearate, they might mask off the underlying layer of copper atoms and thus greatly retard the reaction on the areas which they cover. Another possibility is that different crystal faces, all of which contain sufficient copper to insure complete reaction of an adsorbed stearic acid monolayer, vary greatly in their rates of reaction with the monolayer. Gwathmey has shown that different crystal faces of a copper single crystal are etched differently by lubricating oil containing stearic acid in the presence of air.[10] If either of these explanations is correct, then the division of the cuprite surface among different crystal faces cannot fluctuate greatly since the extent of reaction does not differ too greatly from run to run. At present, however, no really satisfactory explanation of this lack of complete reaction is available.

Whatever the case may be, one can certainly say that lubricants containing stearic acid as a boundary additive will not lubricate copper bearings under conditions of high load (i.e., high local temperatures) or slightly elevated temperatures (70-120 C., melting point of stearic acid to melting point of cupric stearate) as well as they would if all of the stearic acid adsorbed as a monolayer were to react.

It is also of interest to see if copper itself will react with adsorbed stearic acid since any copper or copper alloy bearing which is completely submerged under a lubricant containing a fatty acid during operation will eventually have its oxide film removed by reaction with the acid and the rubbing surface will then expose metallic copper. It has been demonstrated that when a copper surface is cut under a 1% solution of lauric acid in paraffin oil, the fresh metal surface has a high coefficient of friction,[11] which indicates that no reaction does take place. The experimental work described below proves conclusively that adsorbed stearic acid will not react with metallic copper.

A Soxhlet extractor was set up with an inlet tube running to the bottom of the boiler flask. A tank of electrolytic hydrogen was connected to this tube through a flow gauge. A separatory funnel was attached to the top of the extractor condenser so that the funnel contents could be emptied through the condenser into the extractor. There was also a connection so that, after hydrogen passed through the condenser, it could be vented through the funnel, vented to the outside, or passed into the top of the funnel so as to keep the funnel contents under a hydrogen atmosphere. A clean copper coil was placed in the extractor and the system was flushed with hydrogen (0.1 cu.ft./min.) for 10 minutes. The extractor was then heated to 450 C. for six hours by passing an electric current through a nichrome ribbon which was wound around the extractor. During this, and all subsequent operations, a stream of hydrogen was passed through the apparatus. The reduction gave the copper a bright shiny appearance. The coil was then cooled to room temperature and covered with 60 ml. of 0.1% stearic acid in benzene. After standing for several minutes, sufficient benzene was then added to cause the syphon to empty the extractor. The coil was then washed twice with benzene in this same way. Then the coil was extracted by refluxing the benzene solution overnight. The benzene solution was then analyzed for copper in the manner described above. A coil which was treated in this way but which was not extracted with benzene, was removed and tests showed that it was hydrophobic and oleophobic. This indicates that there actually was an adsorbed film on the copper. Blanks were run by carrying out exactly the same sequence of operations with no copper in the extractor. (Note Table II.)

The mean of the runs with copper is 1.40, and that of the runs without copper is 1.88. For this data, application of the "t" test gives t = 1.61 for twelve degrees of freedom. (The "t" test is the standard statistical test for determining if two sets of data are measurements of the identical thing or are really different). For this many degrees of freedom, the critical values of "t" are 1.782 at 10% probability level and 1.356 at 20% probability level. This means that, if the two groups of runs are really both from the same set, one would expect them to differ by at least as much as they do now about 13% of the time. Therefore, we must conclude that the two groups come from the same set and that metallic copper does not react with adsorbed stearic acid.

Furthermore, we can now take the average of these runs, 1.56 μg, as a blank for all copper analyses. The standard deviation of all these runs, 0.49 μg, is likewise the standard deviation of such copper analyses.

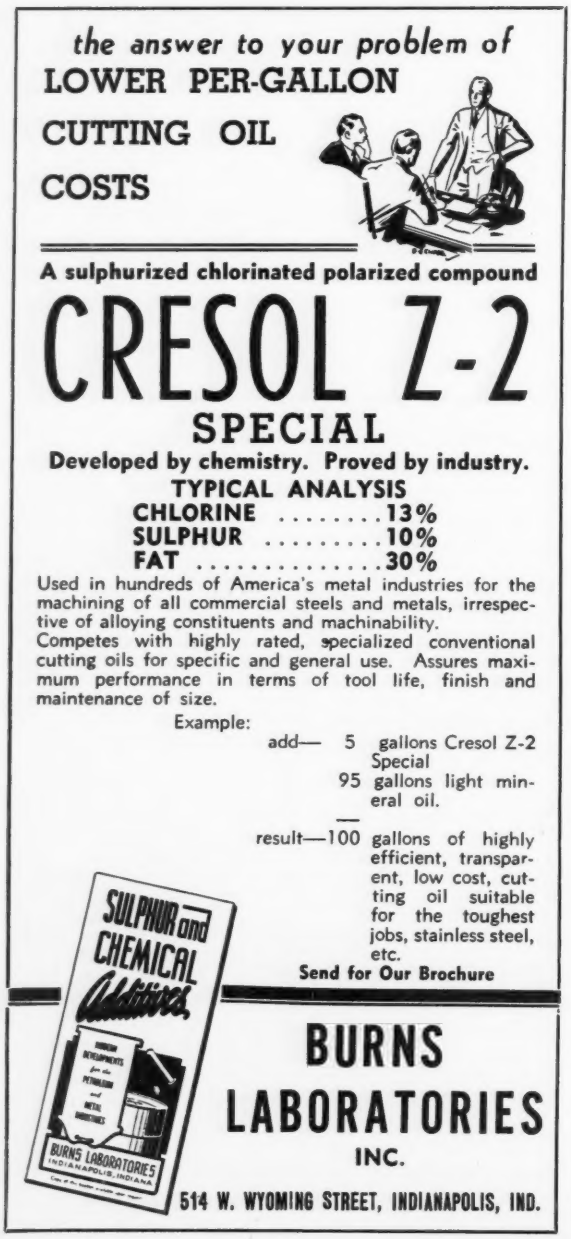
These reactions were also studied by making thermodynamic calculations on the energy of reaction of stearic acid with copper and its oxides under various atmospheres. In order to supply some of the necessary data, the solubility of cupric stearate in water and benzene at 25C. was determined.

The cupric stearate used in these experiments was very carefully prepared by reacting sodium stearate (made from stoichiometric amounts of reagent grade sodium hydroxide and C.P. stearic acid) in water with the stoichiometric amount of reagent grade $CuSO_4 \cdot 5H_2O$. The precipitated soap was then recrystallized twice from benzene. The analysis was as follows:

Calculated for $CuC_{36}H_{70}O_4$: Cu 10.08; C 68.68; H 11.19.
Found: Cu 9.81, 9.82; C 68. 62, 68.68; H 11.42, 11.42.

Solubility determinations were carried out by boiling mixtures of excess cupric stearate with the proper solvent (reagent grade benzene or doubly distilled water) in flasks with ground glass joints, tightly stoppering the flasks and shaking them, along with similar mixtures which had not been boiled, for several days at room temperature. The flasks were then kept overnight at 25C. and the mixtures filtered through Schleicher and Schull No. 507 filter paper (less retentive paper lets some colloidal cupric stearate through). The filtrates were then analyzed for copper in the usual way, save that aqueous solutions were analyzed directly. Standards were run in exactly the same way, using reagent grade $CuSO_4 \cdot 5H_2O$ in water and copper oleate of known composition in benzene. The solubility of cupric stearate at 25C. was found to be $7 \pm 2 \times 10^{-9}$ g./ml. in water and $7 \pm 2 \times 10^{-7}$ g./ml. in benzene.

Daniel[12] gives a value of 1.4×10^{-4} g./ml. for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the solubility of cupric stearate in benzene but this is obviously too large in view of our results.

This data now permits us to make the following thermodynamic calculations:

Reaction of cupric oxide with stearic acid: $C_{17}H_{35}COOH$ (satd. soln. in benzene) + ½ CuO(s) = ½ H_2O (satd. soln. in benzene) + ½ $Cu(C_{17}H_{35}COO)_2$ (satd. soln. in benzene) $\Delta F_{298} = -6.23$ Kcal.

Reaction of cuprous oxide with stearic acid in air: $C_{17}H_{35}COOH$ (satd. soln. in benzene) + ¼ O_2 (air) + ¼ Cu_2O (s) = ½ H_2O (satd. soln. in benzene) + ½ Cu $(C_{17}H_{35}COO)_2$ (satd. soln. in benzene) $\Delta F_{298} = -12.40$ Kcal.

Reaction of copper with stearic acid in air: $C_{17}H_{35}COOH$ (satd. soln. in benzene) + ½ O_2 (air) + ½ Cu (s) = ½ H_2O (satd. soln. in benzene) + ½ Cu $(C_{17}H_{35}COO)_2$ (satd soln. in benzene) $\Delta F_{298} = -21.15$ Kcal.

Reaction of copper with stearic acid in hydrogen: $C_{17}H_{35}COOH$ (satd. soln. in benzene) + ½ Cu(s) = ½Cu $(C_{17}H_{35}COO)_2$ (satd. soln. in benzene) + ½ H_2(g.) $\Delta F_{298} = 7.87$ Kcal.

Under an inert atmosphere, if a saturated (4%) solution of stearic acid in benzene is in contact with metallic copper, virtually no reaction will occur.

Thus, the thermodynamic calculations lead to the same conclusions. Stearic acid in benzene will react with cupric or cuprous oxides but not with metallic copper unless an oxidizing agent such as oxygen is present. However, only about one fourth of a monolayer of stearic acid adsorbed on cuprous oxide will initially react to give cuprous stearate, although eventually thermodynamic equilibrium is established and all of the acid reacts. Of course, these calculations may not apply to a thin film system in which the energy of adsorption is appreciable, but even in this case they may serve as an initial approximation.

Long before equilibrium is established in an actual bearing, however, the physically adsorbed stearic acid will have been rubbed off with a consequent increase in friction. At present, there is no obvious way to improve this situation, although it is evident that some means of speeding up the reaction would be beneficial.

In a copper alloy, such as brass, bronze, or beryllium copper, the thermodynamic calculations will still be valid and eventually the copper or copper oxide will react with stearic acid. However, the extent of the initial reaction may be influenced greatly by other atoms in the oxide lattice. Therefore, different alloys of copper, with the same physical properties, may exhibit entirely different boundary lubricity with fatty acids.

This work also strongly indicates that fatty acids will only act as good boundary lubricants for copper and its alloys so long as oxygen is available. At high altitudes or under conditions where the access of oxygen is prevented, these boundary additives will be ineffective.

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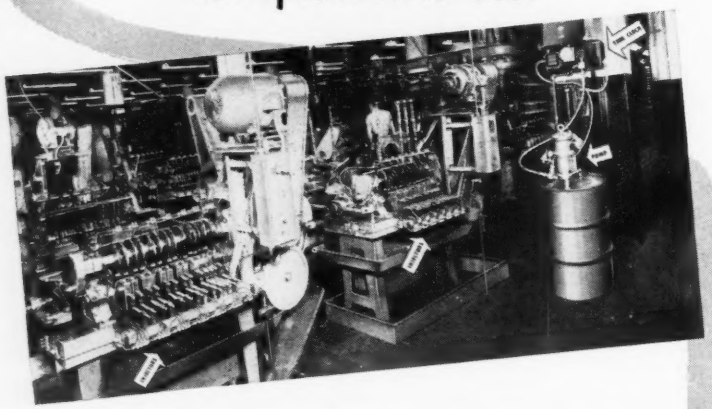

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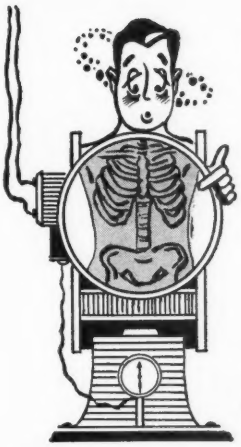
(Lube Summarized, from p. 192)

just below its boiling-point, etch for three to five minutes in an aqueous solution of 50% hydrochloric (muriatic) acid held at 160-180 F., if not clean, repeat degreasing and etching. Dip into flux held at a temperature of 150 F. A saturated solution of two parts of zinc chloride and one part of ammonium chloride in water is usually satisfactory. Dip the shell into a bath of molten bonding alloy (tinner's solder) kept about 150 F. above its liquidus temperature. The shell should have a silvery appearance on removal from the bath. The shell should not be allowed to cool before casting the liner.

In casting, the mandrel and shell should be at temperature higher than 250 F. to eliminate the danger of moisture or steam. The shell should be at a temperature above the melting point of the bonding or tinning metal, the temperature of the mandrel should be approximately 100 F. higher than that of the shell so that solidification can progress from the shell to the mandrel. The stream of metal should be poured against and moved around the circumference of the mandrel to prevent local overheating. Use a ladle of sufficent capacity to permit pouring the entire bearing at one time; this reduces the likelihood of cold shuts, laminations, or folds.

In the installation of bearings, make certain that all foreign particles, such as dirt, metal chips and lint, are wiped from the bearing and shaft with a lint-free material. Make certain that the clearances between the bearing and the shaft are adjusted in accordance with manufacturer's recommendations. Make certain that the shaft and the bearing are



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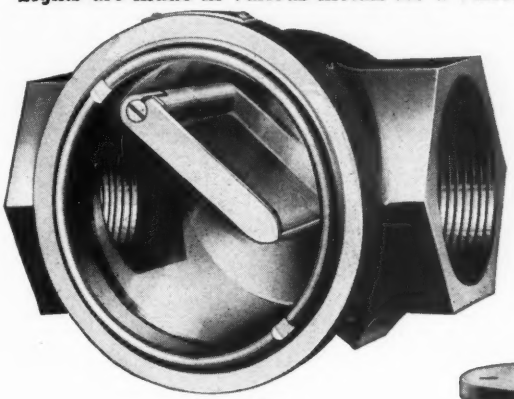

FIG. 811

This vane-type Bowser Indicator is spring-actuated, thus providing an indication of the quantity flowing in the line.

FIG. 811

FIG. 54A

This Bowser Flow Sight is recommended for use on gravity lines where the flow is vertically downward.

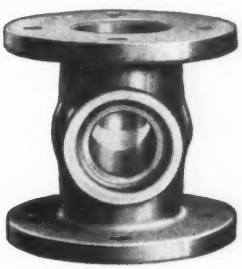

FIG. 54A

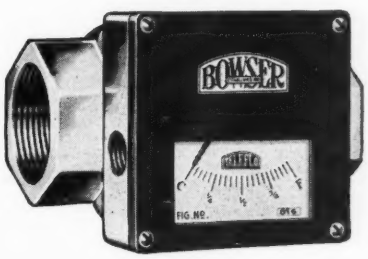

FIG. 816

FIG. 816

The Figure 816 Bowser Teleflo Indicator is equipped to operate a gong or to stop pump motor if liquid flow stops.

Consult with the Bowser engineer nearest you.

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in proper alignment and that the tension of the bolts is even.

In the operation and maintenance of bearings, select the proper lubricant. In most cases the equipment manufacturer has recommended the lubricant found to have the necessary properties. Set up a regular maintenance and inspection schedule for all bearings and follow it closely. Keep your lubricant free of all foreign matter (you bought it that way) by using proper filtering and cleaning devices. Run the equipment at the speed and under the load for which it was designed.

(Current Literature, from p. 204)

of operating conditions, an application table and a selector chart demonstrate how these lubricants can be used to protect against more than 160 corrosive agents and solvents. Other helpful information includes complete data on characteristics, benefits, uses and specifications for each lubricant.

Proper Lubrication — The Life Blood of All Machinery, Lubriplate Div., Fiske Bros. Refining Co. (LE10/4), 129 Lockwood St., Newark 5, N. J., 36 pages.

Valuable treatise on the subject of modern lubrication. (Copy will be furnished by placing request on company letterhead.)

Auto-Klean Filters, Catalog AK-050, Cuno Engineering Corp. (LE10/4), Meriden, Conn.

Describes full line of industrial Auto-Klean filters; principles, construction, and advantages. Specifications and capacities are given for all standard models having flow rates between 1 and 3760 GPM, and normal operating pressures of 125 psi. Conditions requiring other types of filters are also included together with a complete listing of all Cuno offices.

Lubrication Recommendation, Fuller Mfg. Co. (LE10/4), Kalamazoo, Mich.

Represents a condensation of lubrication knowledge Fuller has accumulated from 50 years of experience in manufacturing heavy-duty transmissions for both on- and off-highway trucks and industrial equipment. The feature article, "Proper Lubrication Promotes Profitable Operation," de-

fines the basic functions of transmission lubricants and describes the types and seasonal grades recommended.

Santocel, Inorganic Chemicals Div., Monsanto Chemical Co. (LE10/4), 710 N. 12th St., St. Louis 4, Mo.

Describes the unusual application versatility demonstrated by 20 proven fields of use for Santocel, a silica aerogel. The enormous surface area of the different grades (a cubic inch contains about 500 billion particles) serves to impart a variety of properties to the material. Uses described include those as thickening agents for greases and printing inks, flatting for surface coatings, mold lubricants, dry grinding agent for DDT, anti-caking and bulking agent, as a reinforcing filler for silicone rubber, and as a thickener for polyester and epoxy resins used in low pressure moldings.

Patent Abstracts

Prepared by **Ann Burchick** from **OFFICIAL GAZETTE,** Vol. 681, Nos. 3, 4; Vol. 682, Nos. 1, 2, 3, 4; Vol. 683, Nos. 1, 2, 3. Printed copies of patents are available from the Patent Office at twenty-five cents each. Address the Commissioner of Patents, Washington, D. C. for copies and for general information concerning patents.

Lubricants, Patent #2,672,446, by L. W. Mixon & R. W. Watson, assignors to Standard Oil Co.

A normally liquid lubricant composition comprising a major proportion of a hydrocarbon oil and from about 0.1% to about 20%, by weight, of a copolymer of a dialkyl itaconate in which the alkyl groups contain from about 4 to about 30 carbon atoms, said dialkyl itaconate being an ester of a saturated alcohol and itaconate acid, and an alkyl methacrylate in which the alkyl group contains from about 4 to about 18 carbon atoms, said copolymer having a molecular weight of from about 1000 to about 50,000.

Oxidation Resistant Transformer Oils and the Like, Patent #2,672,447, by W. T. Stewart, C. D. Newnan & N. W. Furby, assignors to California Research Corp.

A transformer oil composition consisting essentially of a major portion of an oil of lubricating viscosity and from about 0.0001% to about 5%, by weight, of a dialkyl monoselenide containing from 12 to 30 carbon atoms in each alkyl group, to which transformer

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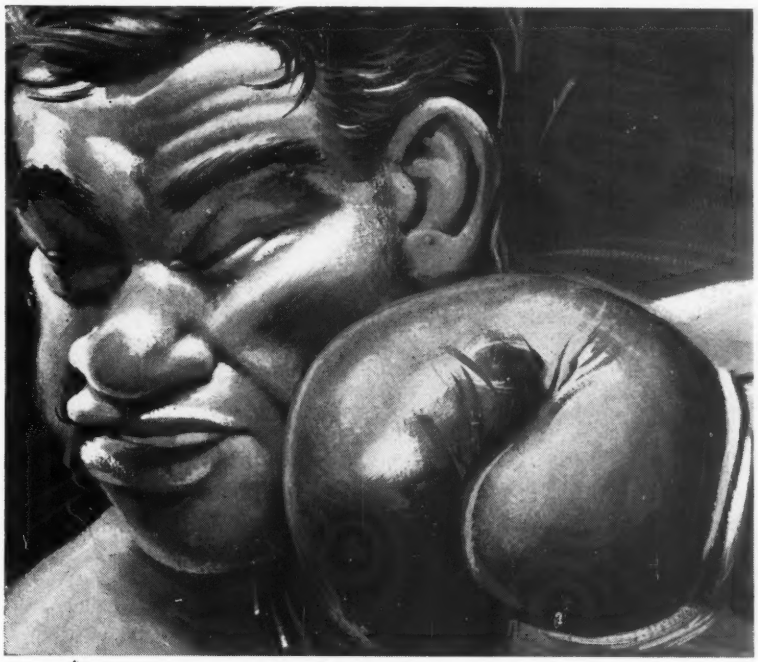

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oil composition is added from about 0.0001% to about 1.0%, by weight, of a hydroxy anthraquinone selected from the group consisting of 1,2-dihydroxy-anthraquinone; 1,4-dihydroxy-anthraquinone; 1,5-dihydroxy-anthraquinone and 1,8-dihydroxy-anthraquinone.

Transformer Oil Containing a Tertiary Alkyl Penol Antioxidant and a Dihydroxy Anthraquinone as a Synergist for the Antioxidant, Patent #2,672,448, by C. D. Newnan & N. W. Furby, assignors to California Research Corp.

A transformer oil consisting essentially of a major portion of a lubricating oil and a minor portion of a combination of a tertiary alkyl phenol antioxidant for said lubricating oil and a synergist for said antioxidant, said antioxidant being present in an amount sufficient to increase the resistance of said oil to oxidation, said synergist being a hydroxy anthraquinone selected from the group consisting of alizarin, quinizarin, anthrarufin, chrysazin, and 2-methyl-1,4-dihydroxy anthraquinone, said synergist being present in the proportion of about 0.002% to about 1.0% by weight of said transformer oil.

Drawing Lubricant Compositions, Patent #2,672,976, by W. A. Overath, R. Kallenbach & H. Fleischhauer, assignors to Parker Rust Proof Co.

A process for the production of lubricants for use in the deformation of of phosphate coated metal comprising the steps of adding water and an alkali metal hydroxide to a material selected from the group consisting of wool fats and wool fats containing fatty acids, heating and agitating the mixture, said hydroxide and water being present in an amount sufficient to form a saponification product having the consistency of a hard soap, and forming an aqueous emulsion of the said saponification product.

Synthetic Lubricating Oil, Patent #2,673,175, by R. K. Stratford, W. A. Jones and F. A. Stuart, assignors to Standard Oil Development Co.

A lubricating oil composition prepared by contacting a solvent extracted, hydrogenated mineral lubricating oil fraction with a gas comprising free oxygen at a temperature of 200-400 F. until a product having a saponification number of at least 20 and not more than about 70 is produced, and treating the oxidized product with a neutralizing agent until the neutralization number of the same is reduced by at least 50% of its original value, said product having the property of inhibiting sludge and varnish formation in internal combustion engines operating for extended periods at low temperatures on deposit forming gasolines.

Metal Cutting Oil Derived from Oxidized Petroleum Oil, Patent #2,673,183, by E. C. Hughes & D. Frazier, assignors to The Standard Oil Co.

A cutting oil comprising a mineral oil base stock and at least about 3% by weight of a neutralized, oxidized, solvent refined, light mineral oil that is substantially free of water and alcohol, at least one of said components having elemental sulfur dissolved therein and said neutralized, oxidized oil component having, before neutralization, a saponification number be-

tween about 20 and 80 and having been neutralized with a base.

Lubricating Grease Prepared from the Esters of the Dimer of Linoleic Acid, Patent #2,673,184, by A. J. Morway, D. W. Young, & D. L. Cottle assignors to Standard Oil Development Co.

A lubricating grease composition which the C_1 to C_{18} alcohol diester of the dimer of linoleic acid thickened to a grease consistency with a lithium soap of a high molecular weight substantially saturated fatty acid.

Lubricating Composition Containing Surface-Esterified Siliceous Solid, Patent No. 2,676,148, by R. K. Iler, assignor to E. I. du Pont de Nemours & Co.

A lubricating composition comprising a water-insoluble lubricating oil, said oil containing carbon as the only group IV element, and being the only lubricating oil in the composition and an organophilic pulverulent solid consisting essentially of substrate particles of inorganic siliceous material in a supercolloidal state of subdivision having chemically bound thereto per 100 square millimicrons of substrate surface at least 100 —OR groups, wherein R is a hydrocarbon radical containing 2 to 18 carbon atoms and the carbon atom attached to oxygen is also attached to at least one hydrogen, the substrate particles having an average specific surface area of from 25 to 900 square meters/gram, and the weight ratio of oil to pulverulent solid in the composition being in the range of 200:1 to 0.1:1.

Stabilized Grease Composition Containing A Sterol & A Selenium Compound, Patent No. 2,676,149, by H. A. Woods & J. A. Edgar, assignors to Shell Development Co.

A grease composition comprising a major proportion of a lubricating oil, a grease-forming proportion of a gelling agent, and minor amounts, but sufficient to increase the operating life of said grease, of a sterol and of a compound.

Corrosion Inhibitors for Lubricating Oils, Patent No. 2,676,150, by G. A. Loughran & E. O. Hook, assignors to American Cyanamid Co.

A hydrocarbon oil composition comprising a relatively large proportion of a hydrocarbon lubricating oil having dissolved therein a relatively small amount, sufficient to reduce the corrosive effect of said composition on metallic elements, of an oil-soluble compound of the group consisting of N,S-substituted dithioammelides and thioammelines.

Textile Lubricants, Patent No. 2,676,924, by F. Fortess & C. Hohing, Jr., assignors to Celanese Corp. of America.

A lubricating and conditioning composition for textile materials comprising 12 to 45% by weight of a partial mixed alkyl phosphate produced by esterifying a mixture of n-decanol, 2-n-butyl hexanol-1 and 2-ethyl octanol-1 in which the total weight of any one alcohol does not exceed 75% of the total weight of all the alcohols, and the average number of alkyl radicals per

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phosphorus atom is 1-½, 30 to 70% by weight of mineral oil, 3 to 25% by weight of a tertiary amine selected from the group consisting of triethanolamine, dibutyl ethanolamine, and dimethyl cyclohexylamine, 1 to 5% by weight of diamyl phenol, and 3 to 25% by weight of the diethanolamino-ethyl ester of cocoanut oil fatty acid.

Method of Dispersing Metal Oxides & Hydroxides in Lubricating Oils, Patent No. 2,676,925, by E. G. Lindstrom & R. L. Woodruff, assignors to California Research Corp.

A process of incorporating polyvalent metal base substances in lubricating oils to produce stable, filterable compositions, which comprises the steps of forming a mixture of a lubricating oil, a dihydric alcohol of less than 6 carbon atoms, an oil soluble polyvalent metal base selected from the group consisting of oxides and hydroxides, said dihydric alcohol being present in the mixture in an amount ranging from 2 to 50 moles for each mole of said inorganic metal base, and heating said mixture for a sufficient time to effect the dispersion of said inorganic metal base in the lubricating oil-dispersant composition and to remove dihydric alcohol.

Rust Preventive Compositions, Patent No. 2,677,618, by E. A. Deiman & A. W. Londert, assignors to Standard Oil Co.

A composition consisting essentially of from about 5% to about 40% of a preferentially oil-soluble sulfonic acid soap selected from the group consisting of a preferentially oil-soluble alkali metal sulfonate, a preferentially oil-soluble alkaline earth sulfonate and mixtures thereof, from about 1% to about 10% of a morpholine soap of an aliphatic mono-basic acid of at least about 12 carbon atoms, and from about 5% to about 80% of a normally liquid hydrocarbon.

Mineral Oil Compositions Having Stabilized Low Pour Points, Patent No. 2,677,659, by O. M. Reiff, assignor to Socony-Vacuum Oil Co., Inc.

A lubricating oil composition having a stabilized low pour point comprising a major porportion of a waxy mineral lubricating oil, a minor proportion, sufficient to lower the pour point of said oil, of a metal salt of an organic acid having a wax-substituted aryl nucleus therein and a minor amount, sufficient to stabilize the lowered pour point of said oil, of an organic acid.

Oil Composition of Improved Pour Stability, Patent No. 2,677,660, by O. M. Reiff, assignor to Socony-Vacuum Oil Co., Inc.

A lubricating oil composition having a stabilized low pour point comprising a major proportion of a waxy mineral lubricating oil, a minor proportion, sufficient to lower the pour point of said oil, of a metal salt of an organic acid having a wax-substituted aryl nucleus therein and a minor amount, sufficient to stabilize the lowered pour point of said oil, of an organic nitrogen compound selected from the group consisting of unsubstituted nitriles and unsubstituted acylic amines.

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Corrosion Inhibitors for Lubricating Oils, Patent No. 2,676,151, by G. A. Loughran & E. O. Hook, assignors to American Cyanamid Co.

A hydrocarbon oil composition comprising a relatively large proportion of a hydrocarbon lubricating oil having dissolved therein a relatively small amount, sufficient to reduce the corrosive effect of said composition on metallic elements of an oil-soluble compound.

Bentonite Greases, Patent No. 2,677,661 by Rosemary O'Halloran, assignor to Standard Oil Development Co.

A process for the manufacture of a new and useful lubricating grease composition consisting essentially of reacting a bentonitic clay with a material selected from the class consisting of high molecular weight primary and quaternary aliphatic amine salts of low molecular weight acids to form a complex reaction product, treating said complex reaction product with a substantially equal volume of a polar material of the class consisting of acetone, ethyl ether, isopropyl alcohol, toluene, xylene, and mixtures thereof, dispersing said treated reaction product in a lubricating oil of the class consisting of mineral oils and silicone fluids by a mixing step, and heating said mixture to a temperature above the boiling point of the polar material.

Lubricating Oil Additives, Patent No. 2,677,662, by L. A. Mikeska, S. B. Lippincott & A. H. Popkin, assignors to Standard Oil Development Co.

A lubricating composition consisting essentially of a major proportion of a mineral lubricating oil having combined therein from 0.05 to 10% by weight based on the weight of the total composition of a copolymer of maleic anhydride and a vinyl alkyl ether containing from 10 to 14 carbon atoms in the alkyl proportion thereof, said copolymer having been esterified with an aliphatic alcohol containing about 14 carbon atoms per molecule, there being at least one alkyl group present in the esterified copolymer having from 8 to 18 carbon atoms in a straight chain.

Production of Anhydrous Soda Base Lubricating Greases, Patent No. 2,678,918, by A. A. Bondi, assignor, by mesne assignments, to Shell Development Co.

A soda soap base lubricating grease containing 0.05% to about 1% of a polyethylene glycol having an average molecular weight in excess of 200, said percentage range being taken on the weight of the grease.

Lubricating Oil Additives, Patent No. 2,678,919, by T. S. Tutwiler & J. H. Bartlett, assignors to Standard Oil Development Co.

A lubricating oil composition consisting essentially of a major proportion of a waxy mineral lubricating oil and about 0.1% to 3.6% by weight of a copolymer of a C_6 to C_{24} alkyl ester of itaconic acid and a compound.

Flushing Compositions, Patent No. 2,678,920, by O. L. Brandes & C. B. Pattinson, Jr., assignors to Gulf Research & Development Co.

A flushing composition consisting essentially of a homogeneous mixture of about 5 to about 60 per cent by weight of isopropylphenol; about 10 to

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about 60 per cent by weight of a mineral lubricating oil; about 5 to about 40 per cent by weight of a water-soluble metallic soap of a fatty acid, said soap containing about 20 to about 60 per cent by weight of water; and water in an amount sufficient to produce a flushing composition having a total water content between about 2 and about 30 per cent by weight.

Indogen Thickened Grease Composition, Patent No. 2,679,480, by C. G. Brannen & E. A. Swakon, assignors to Standard Oil Co.

A lubricant grease comprising essentially a lubricant vehicle thickened with an amount of from about 10% to about 70% by weight of an indogen compound melting above about 250 F.

Rust Preventive Oil Composition, Patent No. 2,680,094, by J. H. Bartlett, A. D. Kirshenbaum & H. W. Rudel, assignors to Standard Oil Development Co.

A rust inhibiting composition consisting essentially of 95 to 99.9% by weight of mineral base lubricating oil, 0.05 to 4.5% oil-soluble metal base petroleum sulfonate, and 0.005 to 1% of aliphatic alcohol esters of ethylene bisimino diacetic acid having at least 8 and not more than about 18 carbon atoms in each alcohol group.

Low Temperature Grease Compositions, Patent No. 2,680,095, by B. W. Hotten & R. J. Houston, assignors to California Research Corp.

A grease composition comprising a mixture of a polysiloxane oil and a polyoxyalkylene oil, and a grease thickening agent in an amount sufficient to thicken the oil mixture to the consistency of a grease, said polyoxyalkylene oil being present in an amount sufficient to improve the dispersibility of said thickening agent in said polysiloxane oil.

Making Sulfonates Suitable for Use in Soluble Oil, Patent No. 2,680,716, by M. R. Lipkin & H. E. Reif, assignors to Sun Oil Co.

Method for preparing soluble oil which comprises: sulfonating mineral lubricating oil having S.U. viscosity at 100 F. within the approximate range 200-1000 seconds, with gaseous SO_3 at a temperature within the approximate range 180 F. to 300 F., while maintaining the ratio of gaseous SO_3 to oil within the range from 0.1 to 2.5 moles of gaseous SO_3 per mole of aromatics in the oil, thereby to produce mahogany sulfonic acids; separating said mahogany sulfonic acids from green sulfonic acids; saponifying such separated mahogany sulfonic acids with an alkali metal base, thereby to form alkali metal mahogany sulfonates; and blending petroleum oil with the saponified mahogany sulfonic acids to obtain a soluble oil containing a major proportion of petroleum oil.

Rust Inhibiting Composition, Patent No. 2, 680,718, by L. T. Eby, assignor to Standard Oil Development Co.

A composition consisting essentially of a hydrocarbon solvent containing dissolved therein 0.01 to 10% of a monoester of a C_{12} to C_{24} unsaturated fatty acid with a polyhydroxy aliphatic compound containing 5 to 6 carbon atoms and having 4 to 6 hydroxyl groups attached to carbon atoms separated from each other by not more than one carbon atom containing no hydroxyl group, which monoester has been sulfurized by a reaction with elementary sulfur.

Alkyl Orthosilicate & Alkoxysiloxane Base Grease Compositions, Patent No. 2,681,313, by W. S. Kather & T. Wiener, assignors, by mesne assignments, to California Research Corp.

A composition of matter, a grease containing 95% to 75% by weight of an alkyl orthosilicate and 5% to 25% by weight of soaps, said percentage totaling 100%.

Process for an Inorganic Colloid Thickened Grease, Patent No. 2,681,314, by J. R. Skinner & W. E. Savage, assignors to Shell Development Co.

The process for the preparation of a lubricating grease composition which comprises heating a mixture of a hydrophobic aliphatic amine and a silica hydrogel at a temperature between about 70 and about 100 C. for a period between about 45 minutes and 4 hours, filtering at least 25% of the water from said mixture after heating, commingling the partially dehydrated mixture with a water-insoluble lubricating oil and substantially completely dehydrating the resulting grease composition.

Lubricating Oil Composition, Patent No. 2,681,315, by C. O. Tongberg & W. H. Brugmann, Jr., assignors to Standard Oil Development Co.

A composition of matter comprising a major amount of a mineral lubricating oil and, based on total composition, about 0.4 to 10% by weight of calcium

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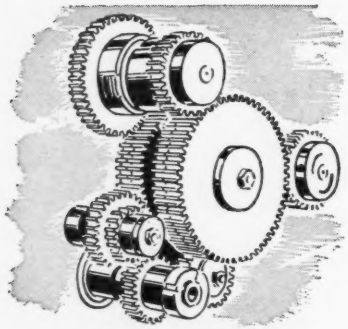

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petroleum sulfonate, about 0.05 to 4% by weight of an oil miscible alkylphenoxypolyethoxyethanol having from 2 to 6 ether groups, and 0.2 to 10% by weight of an alkaline earth metal salt of an alkyl phenol sulfide.

Oil Compositions Stabilized Against Oxidative Deterioration, Patent No. 2,681,316, by O. L. Harle, assignor to California Research Corp.

An oil composition having improved stability toward oxidation consisting in major portion of a normally oxidizable oil, together with from about 0.1 to 1% by weight of a sulfur-containing compound selected from the group consisting of tetramethyl thiouramdisulfide and di-sec.-butyl xanthogen and about 0.1 to 2% by weight of a hydroxy-substituted aromatic hydrocarbon selected from the group consisting of 2,2'-di(p-hydroxyphenyl) propane and p-tert.-butyl-catechol.

Coming Events

AUGUST

16-18 Society of Automotive Engineers (national West Coast meeting), Statler Hotel, Los Angeles, Calif.

SEPTEMBER

8-10 American Society of Mechanical Engineers (Fall meeting), Schroeder Hotel, Milwaukee, Wisc.

12-16 American Institute of Chemical Engineers, Colorado Hotel, Glenwood Springs, Colo.

12-16 Society of Automotive Engineers (national tractor meeting), Schroeder Hotel, Milwaukee, Wisc.

12-17 American Chemical Society, New York, N. Y.

15-17 American Petroleum Institute Lubrication Committee, Traymore Hotel, Atlantic City, N. J.

15-17 National Petroleum Association (52nd Annual Meeting), Traymore Hotel, Atlantic City, N. J.

27-28 Independent Oil Compounders Association (annual meeting), Hotel Sheraton, Chicago, Ill.

27-29 American Institute of Electrical Engineers (Conference for Petroleum Industry), Mayo Hotel, Tulsa, Okla.

27-30 American Society of Mechanical Engineers (annual engineering conference), Statler Hotel, Los Angeles, Calif.

OCTOBER

3-7 ASTM Committee D-2 on Petroleum Products & Lubricants, Sheraton Park Hotel, Washington, D. C.

4-9 Society of Automotive Engineers (national aeronautic meeting), Statler Hotel, Los Angeles, Calif.

18-19 Joint ASME-ASLE Conference on Lubrication, Lord Baltimore Hotel, Baltimore, Md.

APRIL, 1955

13-15 American Society of Lubrication Engineers (10th Annual Meeting & Exhibit), Hotel Sherman, Chicago, Ill.

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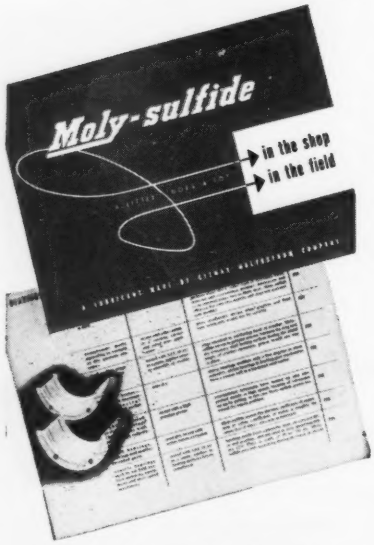

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COMMENTARY on "The Boundary Friction of Very Well Lubricated Surfaces" (E. Rabinowicz, p. 205) by M. B. Peterson & E. E. Bisson, NACA Lewis Flight Prop. Lab.

The development of theory and the experimental results presented in this paper are very interesting. The data are of particular interest to NACA since we have been interested in lubrication with various solids for some time. The results presented in the paper are in general agreement with those we have obtained for several inorganic solids. The experimental verification of the point that friction coefficient at constant pressure is independent of the nature of the harder metal is quite striking, even though the scatter band does not always hold to the 20% value.

It would seem, however, that the quantitative value of 20% has been stressed too highly in view of the many uncertainties involved in its determination. This is particularly true when it is considered that its actual value is not significant. The main point seems to be that, for a 'well lubricated surface,' the metallic friction is small in comparison to the shear within the lubricant film and consequently the friction properties are primarily a function of the lubricant.

In reading this paper several questions arose. First what was the maximum difference between the minimum and the maximum value of friction coefficient in a single run? The trace shown in Fig. 2 would seem to indicate that this difference was very small; is this true of all the tests at various speeds? If this difference is appreciable, considerable error could be introduced into the data by choosing the **minimum** value. This would be particularly true if sliding were of the 'stick-slip' type or if the force measuring system had a slow response.

In order to correlate with some of the NACA results, it would be interesting to know the conditions of the specimens and the film during sliding and especially at the time when the friction force was measured. At this time was there any evidence of wear on the slider or metal contact through the film on the disk? It seems unusual that friction force should vary periodically in each revolution if metallic contact is taking place. From our experience, the author's explanation which attributes this periodic effect to lapping marks seems more plausible, the difference in friction being the result of trapping of lubricant when sliding perpendicular to the lapping marks. For example, NACA results with an inorganic solid on a ground steel surface showed variations of friction coefficient from 0.25 to 0.1 in sliding perpendicular to and parallel to the grinding marks, respectively.

The data of Fig. 6 show that indium which is softer than lead gives a lower coefficient than lead. Is it possible that some reaction may be taking place between the lubricant and the various surfaces which would partially explain such a result?

M. B. Peterson & E. E. Bisson

AUTHOR'S CLOSURE: Answering in turn the important questions raised by Messrs. Peterson & Bisson, I would state that for a series of runs at the same velocity the maxima showed greater variation than the plotted minima, but that use of average coefficients of friction as data points would have led to curves of the same shape, but with somewhat higher scatter and higher values of f. The response of the measuring system was more than adequate except, perhaps, at the highest velocities used. 'Stick-slip' did not occur — indeed for most of the experiments the f - v curve had a positive characteristic, and this rules out any possibility of stick-slip.

There was no evidence of pronounced wear or metallic contact during the experiments, though a very small amount of metal contact seems inevitable. The rise and drop in friction as the rider slides along and across the lapping marks gives rise to a small periodic component in the friction trace of twice the frequency of rotation of the specimen, and this component may be seen in Fig. 2 of the paper. The explanation given by the discussors for this important phenomenon is undoubtedly correct.

There was some evidence of chemical reaction between the copper palmitate, when molten, and the underlying metal, particularly in the case of lead, in which case the surface of the lead became discolored on prolonged heating. However, a plot equivalent to Fig. 6 could have been obtained using only data for lead, indium and zinc sliding on a copper palmitate film on copper, in which case reaction of the metal of the rider with the cold film of lubricant seems unlikely.

E. Rabinowicz

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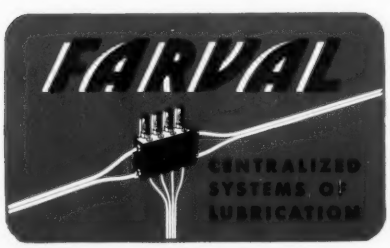

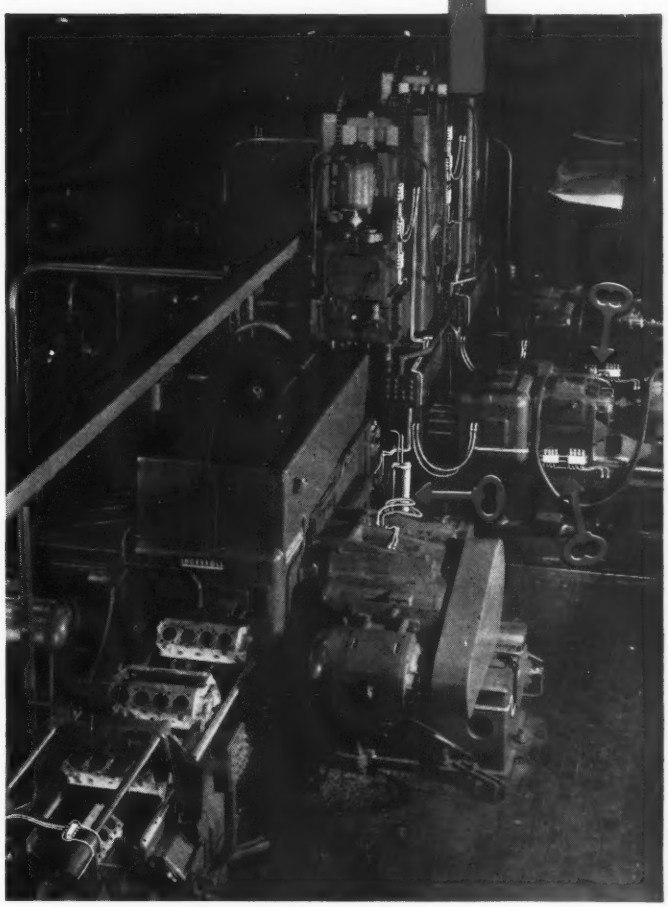

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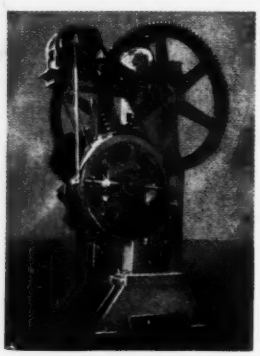
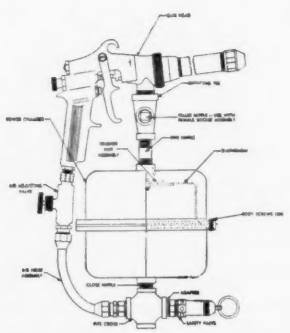


Open Gearing of Mechanical Presses



Hodson Power Grease Spray System for Portable Applications

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